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A Critical Review of Wastewater Treatment Plant Sludge Disposal by Landfilling

Calscience Research, Inc.
Huntington Beach, CA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Oct 82

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October 1982

A CRITICAL REVIEW OF WASTEWATER TREATMENT PLANT SLUDGE DISPOSAL BY LANDFILLING

by

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Contract No. 68-03-2886

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This report evaluates the landfilling of wastewater treatment plant sludge for purposes of describing current practices, determining environmental and public health impacts, describing available control technology, and evaluating management options. The potential environmental/public health impacts and operational problems associated with current sludge landfilling practices are described. Potential public health risks from sludge landfilling are associated with contaminants entering ground or surface water. Environmental and public health risks associated with ludge landfilling can be significantly reduced by utilizing current available control technology. Stabilization of sludge may or may not be necessary, depending on the landfill site and design, but sludge dewatering is considered imperative for all landfilling operations to avoid problems in landfill operations and leachate generation.

KEYWORDS: *Sludge disposal, *Earth fills, *Water pollution control.

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16. ABSTRACT

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is the first necessary step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollution discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report evaluates the landfilling of wastewater treatment plant (WWTP) sludges for the purpose of describing current practices, determining adverse impacts and beneficial uses, describing available control technology, and management options for landfilling sludges.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

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ABSTRACT

This report evaluates the landfilling of wastewater treatment plant sludge for purposes of describing current practices, determining environmental and public health impacts, describing available control technology, and evaluating management options. This assessment was based on a review of existing literature regarding the disposal of municipal sludge and refuse to land.

Current sludge landfilling practices include sludge-only trenches, sludge-only area fill methods (disposal above ground level), and codisposal methods containing an admixture of sludge and refuse or soil. The potential environmental/public health impacts and operational problems associated with each method are described.

The major potential environmental impacts associated with sludge landfilling are the production of contaminated leachate and surface water runoff, the production of noxious odors, and possible spoiling of land by landfill construction. Because of the potential for degradation of valuable water resources, review efforts focused on possible water quality impacts. A comparison of sludge-only, refuse-only, and sludge/refuse codisposal landfill leachate compositions showed considerable disparity. Refuse-only landfill leachates tend to exhibit higher concentration ranges for TOC, TS, Ca, total Fe, Zn, Cd, fecal coliform, fecal streptococci, and a lower pH range than sludge-only and codisposal leachates. In comparing sludge-only and codisposal landfill leachates, codisposal leachates tend to show higher concentration ranges of COD, dissolved solids, Cl, total Fe, Zn, and a wider pH range than sludge-only leachates. Sludge-only leachates show substantially higher concentrations of NO_3-N than either refuse-only or codisposal leachates. In terms of leachate volume, a simple water balance model indicated that municipal sludge can generate large volumes of leachate from compaction and decomposition processes. Municipal refuse can absorb large volumes of sludge moisture, thus preventing or delaying attainment of landfill field capacity.

Potential public health risks from sludge landfilling are largely associated with contaminants entering ground or surface water. The potential health risks associated with aerosols, and vectors need to be further investigated. Environmental and public health risks associated with sludge landfilling can be significantly reduced by utilizing current available control

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This report was submitted in fulfillment of Contract No. 68-03-2886 by Calscience Research, Inc. under the sponsorship of the U.S. Environmental Protection Agency.

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SECTION 1

INTRODUCTION

The treatment of municipal wastewaters for pollutant removal produces not only a relatively clean water for discharge, but also a significant quantity of residue material. The disposal of municipal wastewater treatment plant (WWTP) sludge* is a growing problem in the United States. The nation's 15,000 publicly owned treatment works produce an estimated 6 million dry metric tons of wastewater sludge annually, with this figure expected to rise to about 10 million dry metric tons by 1990 (1). Stringent sludge disposal requirements coupled with the high costs of disposal present a complex social and technological challenge.

Disposal of wastewater treatment plant sludge has historically occurred by land burial, ocean dumping, internment in evaporative (or percolation) type lagoons and ponds, incineration, agricultural utilization, and landspreading. Current bans on ocean dumping of sludge and the high costs of incineration have stimulated interest in landfilling. Landfilling operations currently account for approximately 25 to 30 percent of the total quantity of sludge disposed of in the United States (2,3).

Landfilling of sludge is accomplished either with or without municipal refuse and presents a number of potential environmental/public health risks, and managerial options. Environmental/public health risks include such problems as leachate contamination of water and soil resources, destruction of native fauna and flora, obnoxious odors, aerosol and dust generation, pathogen transmission, and other related nuisances. Management decisions for sludge landfills encompass a range of topics uncommon to conventional refuse landfills, including selecting acceptable types of sludge for landfilling, determining the degree of sludge stabilization or dewatering required, and estimating appropriate sludge/refuse mixing ratios for codisposal. The degree of environmental/public health risk posed by sludge landfills will be greatly influenced by such management decisions.

The purpose of this project is to evaluate critically the literature dealing with WWTP sludge landfilling in terms of the following:

---

* The term "residual" used in this report is synonymous with "sludge".

- Current sludge disposal practices;
- Potential environmental and public health impacts;
- Available control technology; and
- Management options.

Land treatment and agricultural uses of sludge are not considered in this evaluation. This report provides design engineers, regulatory officials, and other interested parties practical information which can be applied to existing and future sludge landfill sites.

The report is composed of the following sections. Section 2 presents the general conclusions and recommendations of the study. Section 3 reviews the characteristics of wastewater treatment plant residuals. Section 4 outlines the current sludge landfilling practices. Section 5 presents an assessment of the potential environmental impacts resulting from sludge landfilling practices. The potential public health impacts associated with sludge landfilling are presented in Section 6. Section 7 presents a review of the available pollution control technology applicable to sludge landfills. Sludge landfilling management options are presented in Section 8.

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SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Landfilling of municipal WWTP sludge entails some risk of damage to the environment and public health. The degree of risk is site specific for each landfilling situation. The assessment of risk involves considerable uncertainty due to lack of adequate information concerning environmental effects, the potential for transmission of sludge contaminants from landfilling operations to humans, and the susceptibility and immunity of the human host to infection and/or disease.

The environmental/public health risks related to sludge landfilling are controlled by sludge characterisitcs, site selection, landfill design, and operation and maintenance. Sludge characteristics are believed to be the key factor in gauging potential impacts. Proper site selection and landfill design operations can minimize the environmental and public health risks. The risks can be substantially reduced if toxic and pathogenic constituents can be eliminated from sludge.

The reviewed literature revealed a number of apparent trends and information deficiencies regarding sludge landfilling. The major environmental risk of sludge landfill is the potential degradation of ground water and surface waters by contaminated leachates. A comparision of sludge-only, refuse-only, and sludge/refuse codisposal landfill leachate compositions showed considerable disparity. Refuse-only landfill leachates tend to exhibit higher concentration ranges for TOC, TS, Ca, total Fe, Zn, Cd, fecal coliform, fecal streptococci, and a lower pH range than sludge-only and codisposal leachates. In comparing sludge-only and codisposal landfill leachates, codisposal leachates tend to show higher concentration ranges of COD, dissolved solids (specific conductivity), Cl, total Fe, Zn, and a wider range than sludge-only leachates. Sludge-only leachates show higher concentrations of NH_3-N and NO_3-N than either refuse-only or codisposal leachates. Leachates from refuse-only, sludge-only, and codisposal landfills are of sufficient strenth to seriously degrade the quality of receiving waters.

The risk of transmitting disease through sludge landfilling operations is highly speculative because of the paucity of

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reliable epidemiological evidence. Quantitative data addressing disease transmission from sludge landfills are generally not available. Potential pathways of direct contaminant transmission from landfills to man include aerosolization, vector transport, direct contact, surface water runoff, and ground water. Contamination of ground and surface waters are believed to present the greatest public health risk from sludge landfills, particularly if ground and surface waters represent a potential source of drinking water, irrigation water, or surface water supporting aquatic life. Sludge pathogens can remain viable in soils and water for days, and have been shown to travel considerable distances in ground and surface water media. The opportunity for human exposure to sludge will govern the risk of contaminant transmission via aerosols, vectors, and direct contact, the opportunity being greatest for workers at the site, less for visitors, and less still for those who live near the site. The public health risk is also related to host susceptibility and immunity.

Various environmental and operational problems can occur at sludge landfills which are not common to refuse-only landfills. Many of these problems are related to sludge moisture. At codisposal landfills, sludge moisture in excess of the refuse adsorptive capacity can accelerate leachate production. Aside from net infiltration to the landfill, the amount of leachate producible at a sludge-only landfill site can be quantitatively estimated from the initial sludge moisture content, landfill depth, and the susceptibility of sludge to change through biological and physical alteration. Estimates of leachate production from codisposal landfills must additionally consider the effects of refuse adsorption and decomposition. Sludge odor problems can also be related to the sludge moisture content. Operational problems associated with sludge moisture include limited sludge support capabilities (i.e., for cover soil and equipment), slumping, and equipment slippage. To diminish these adverse effects, sludge is usually dewatered prior to transport to the landfill site.

Sludge stabilization can minimize potential environmental and public health impacts at landfill sites. Stabilization can reduce sludge odor, putrescibility, and pathogen levels. Of the sludge stabilization alternatives, anaerobic digestion and high lime treatment (pH >11.5) offer distinct advantages which include methane recovery (anaerobic digestion only), leachate composition control (both), and odor control (both). Pasteurization, heat drying, and high energy radiation processes can eliminate sludge pathogens. Whether sludge stabilization is necessary for landfilling operations is site specific.

Landfilling costs compare favorable with other disposal options, including incineration and land application processes. A significant economic constraint to landfilling is the haul distance from the wastewater treatment plant to the landfill.

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Of the sludgelandfilling options, sludge/refuse codisposal options were found the least expensive, followed by trenching operations, diked containment, and area fill operations. Capital costs for sludge landfilling operations are site specific, and include land purchase, site preparation, equipment purchase, and engineering. Operation and maintenance costs for landfilling may exceed those of other sludge disposal options.

Sludge landfill sites can be established and maintained without substantial environmental and public health impairment. The major factors governing the environmental/public health risks include sludge characteristics, site selection, landfill design, and subsequent site construciton, maintenance, and monitoring.

RECOMMENDATIONS

1. When the quality of sludge destined for landfills need to be improved, effective means of improvement are:

   (a) Source control or pretreatment to reduce the introduction of toxic materials into the sludge; and

   (b) Treatment before disposal to reduce soluble contaminants and pathogens

2. Dewatering is recommended for all sludges destined for landfilling. The degree of dewatering required is site specific.

3. Sludge stabilization may or may not be necessary for landfilling operations, depending on the site and the results of future epidemiological studies. Some degree of stabilization, particularly for pathogen reduction, is recommended.

4. Where feasible, landfilling an admixture of sludge and refuse is recommended to minimize sludge leachate production and disposal costs. The sludge moisture content should not exceed the refuse adsorptive capacity.

5. Cover soils should be applied to exposed sludges, as frequently as possible to avoid odor, vector, and aerosol threats to site operations, visitors, and the surrounding community.

6. Leachate, ground water, and surface water control measures and monitoring should be implemented for sludge landfills, particularly for geographical

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areas of the United States where receiving waters may be threatened by the leachates.

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SECTION 3

CHARACTERISTICS OF WWTP SLUDGE

The physical, chemical, and microbiological quality of sludges from municipal wastewater treatment plants is dependent upon the nature of incoming raw wastewater and the effectiveness of the treatment train employed. A major portion of the sludge generated is biodegradable, and measurable quantities of persistent organics, metals and minerals are also invariably present. The sludge may contain pathogenic organisms which survive wastewater treatment processes. Without industrial wastewater pretreament, industries may be the major source for contributing trace metals, refractory organics, or salts to the WWTP sludges.

The purpose of this section is to describe the nature and properties of sewage sludges resulting from various wastewater and sludge treatment processes. Because of the important influence of industrial discharges on the quality of sludge generated, efforts were made to distinguish whether cited sludge data included industrial wastewater contributions. The discussion has been kept brief, inasmuch as detailed information on the subject is available in other reference material (4-11).

TYPES OF WWTP SLUDGE

WWTP sludge is generally classified according to the stages of wastewater treatment incurred, such as primary, secondary, or tertiary. Additionally, it may be categorized by the various sludge treatment processes, including thickening, stabilization, disinfection, conditioning, dewatering, drying, and high temperature processing. Within each of these categories are numerous process alternatives.

Sludge Production: Wastewater Treatment

Primary Sludge--

Primary treatment of wastewater refers to the use of primary sedimentation to remove readily settleable solids from raw wastewater. The sludge resulting from the sedimentation process is called primary sludge or raw sludge. Primary sludge generally varies from 3 to 7% solids depending on the operating efficiency of the clarifier and on the nature of the solids.

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A sludge containing large amounts of fine, nonvolatile solids, such as silt from storm inflow, can attain concentrations well over 6% (6,12). Industrial loads from food processing industries have increased primary sludge concentrations to 17% solids (13). The effects of various other industrial contributions are not reported.

Table 1 lists some of the chemical and biological characteristics of primary sludge. The high volatile solids content is indicative of the organic nature of primary sludge. Primary sludge usually contains over 100 different types of anaerobic and facultative species of bacteria (14). Sulfate-reducing and oxidizing bacteria, worm and fly eggs, and pathogenic microorganisms are typically present.

There are several reasons why primary sludge is usually easier to manage than biological or chemical sludges, described below. First, primary sludge is readily thickened by gravity, whereas biological sludges are difficult to thicken by gravity (8,10). Solids-liquid separation of digested primary sludge is downgraded by even small additions of biological sludge (8). Second, in comparison with biological and many chemical sludges, primary sludge can be dewatered rapidly to produce a drier cake with lower conditioning requirements (8,10,11,15). Nevertheless, primary sludge is frequently mixed with biological and chemical sludges for combined sludge treatment.

Secondary Sludge--

Secondary wastewater treatment processes produce residues which are commonly referred to as biological or chemical sludges; these sludges differ from primary sludge by their cellular nature (biological sludge) and chemical additions (chemical sludge). Biological sludges are produced in treatment processes such as activated sludge, trickling filters, and rotating biological contactors (RBCs). Chemicals are widely used in wastewater treatment to precipitate and remove phosphorus, and in some cases, to improve suspended solids removal. Characteristics of these sludges are described below.

Biological Sludge--Activated sludge processes use a suspension of aerobic microorganisms to digest soluble and colloidal organic matter. Sludges from these processes range from about 0.5% up to 2% solids depending on the operating efficiency of the clarifier. Compared to primary sludge, activated sludge contains higher amounts of nitrogen, phosphorus, and protein, while the grease, fats, and cellulose are lower (Table 1). Volatile solids content range from 60 to 80% (8). The activated sludge process is capable of some inactivation of viruses and probably has some effect on bacterial pathogens as well (21).

Trickling filters and RBCs are used for the same basic

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TABLE 1. CHEMICAL AND BIOLOGICAL PROPERTIES OF VARIOUS SLUDGES (15)

	Raw Primary Sludge		Raw Activated Sludge		Trickling Filter Humus		Digested Sludge		Reference
	Range	Median	Range	Median	Range	Median	Range	Median	
Total Solids (TS) (%)	3-7	5	1-2	1	2-7	4	6-12	10	(11)
Volatile Solids (% TS)	60-80	70	60-80		50-80		30-60	40	(11)
Grease and fat (% by weight of dry solids)	5-35		5-12			6	3-20		(16)
Cellulose (% by weight of dry solids)	3.8-15	10		7			0.6		(16)
Lignin (% by weight of dry solids)	5-8							8.4	(16)
Protein (% by weight of dry solids)	20-30	25	32-41				16-41		(16)
Nutrients (% dry-weight)									
Nitrogen	1.5-8	3	4.8-6	5.6	1.5-5	3	1.6-6	3.7	(11)
Phosphorus	0.8-2.7	1.6	3.1-7.4	5.7	1.4-4	3	0.9-6.1	1.7	(11)
Potassium	0-1	0.4	0.3-0.6		0.1		0.1-0.7		(11)
pH	5-8	6					6.5-7.5	7	(11)
Alkalinity (ppm $CaCO_3$)	500-1,500	600					2,500-3,500	3,000	(11)
Metals (ppm dry weight)									
Arsenic							3-30	14	(17)
Cadmium							5-2,000	15	(18)
Chromium							50-30,000	1,000	(18)
Copper			385-1,500	916			250-17,000	1,000	(18)
Lead							136-7,600	1,500	(17)
Mercury							3.4-18	6.9	(17)
Nickel							25-8,000	200	(17)
Selenium							1.7-8.7		(17)
Zinc			950-3,650	2,500			500-50,000	2,000	(17)
Persistent Organics (ppm dry weight)									
PCBs							1.2-105	3.2	(18)
Chlordane							3-30		(18)
Dieldrin							0.3-2.2	0.16	(18)
Pathogens								0.05	(19)
Virus (PFU/100 ml)		7.9						0.4	(20)
Coliform	11.0-11.4		2-2.8			11.5			
10^6/100 ml)						93		29	(20)
Salmonella		460	74-23,000						
(per 100 ml)								34	(20)
Pseudomonas		46,000	1,100-24,000			11,000			
(per 100 ml)									

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purpose as the activated sludge process, i.e., to remove BOD_5 and suspended solids. The characteristics of trickling filter and RBC sludges are generally similar to those of activated sludges.

Chemical Sludge--Chemical addition to primary and secondary treatment processes increases the resulting sludge mass (and usually its volume) with the additional settled colloidal matter and suspended solids from the wastewater and the settled chemicals themselves. Aluminum and iron salts, lime, and organic polymers are frequently employed to enhance the removal of colloidal material, suspended solids, and phosphorus in primary, secondary, and tertiary processes. Generally speaking, lime and polymer addition results in a sludge that thickens and dewaters better than the same sludge without chemicals. However, when iron or aluminum salts are added to raw wastewater, primary sludge does not thicken or dewater as well as non-chemical sludge (22). Conversely, aluminum salts added to activated sludge will improve its thickening ability (23,24).

Tertiary Sludge--

Tertiary treatment of municipal wastewater involves the removal of potential contaminants such as nitrogen, phosphorus, heavy metals, and organics, yielding new settleable solids. The pathogens that remain after secondary treatment are likely to settle with these new solids, though present at lower levels than in primary or secondary sludges. Where excess lime treatment is used, the high pH is likely to exert a significant anti-microbial effect (25).

Miscellaneous Wastewater Solids--

In addition to the primary, secondary, and tertiary sludges above, there are several other wastewater solids removed at various stages of wastewater treatment. These include:

- Screenings--solids such as rags, sticks, and debris in the raw wastewater that are removed on racks or bar screens placed at the head of the treatment plant. Screenings typically have a moisture content of 80 to 95% and an organic content (dry weight basis) of 70 to 80% (26).

- Grit--heavy, coarse solids such as sand, gravel, coffee grounds, seeds, etc. that are selectively removed at the head of the wastewater treatment plant in gravity settling chambers or air flotation tanks. Grit has a reported moisture content ranging from 13 to 65%, and a volatile solids content of 1 to 56% (8). Grit is often washed with water after collection to reduce the putrescibility.

- Skimmings--material that floats on wastewater in preaeration tanks, skimming tanks, sedimentation basins, gravity thickeners, and digesters. Treatment of skimmings in digesters is common, particularly with mixed units. The moisture content of skimmings is highly variable, depending on its source and treatment, ranging from 36 to over 90% (8). Volatile solids usually comprise greater than 90% of skimmings.

Ordinarily, screenings, grit and skimmings should be regarded as containing pathogens unless disinfected (8,27).

Sludge Treatment

The basic sludge treatment processes and their function are outlined in Table 2. A brief description of those processes representing distinct changes in the physical, chemical, or pathogenic nature of the sludge follows.

Thickening--

Thickening processes remove water from sludge via gravity, air flotation, or centrifugation mechanisms. In general, a reduction in sludge volume and an increase in sludge solids content are the major changes effected in the sludge during thickening. Sludge thickening processes normally increase sludge solids content to between 2 and 7%, though gravity thickening of thermally conditioned and lime treated (high lime, pH >12.0) sludges can increase solids content above 10% (9). However, even at these higher solids concentrations, sludges are normally further dewatered (described below) prior to landfilling. Thickening may provide a blending function in combining and mixing primary and secondary sludges.

Stabilizing--

The extent to which a sludge is stabilized prior to landfilling may have a pronounced effect upon leachate and gas generation and composition. The principal purposes of stabilization are to make the treated sludge less odorous and putrescible, and to reduce the pathogenic organism content. Since the risks of odor and disease transmission are among the primary concerns related to sludge landfilling, stabilization is a key process in sludge landfill management. Some procedures used to accomplish this objective can also result in other basic changes in the residual composition. The major stabilization processes include:

- Anaerobic and aerobic digestion--the biological degradation of sludge resulting in a partial conversion of organic matter into liquid, dissolved solids, and gaseous by-products. Digestion can reduce volatile solids by 30 to 60%, can greatly reduce odor levels in

TABLE 2. SLUDGE TREATMENT PROCESSES AND FUNCTIONS (28)

Unit Processes	Functions
Thickening	Water removal Volume reduction Post process efficiencies Blending
Stabilizing	Pathogen destruction Volume and weight reduction Odor control Putrescibility control Methane production (anaerobic digestion)
Disinfecting	Pathogen destruction
Conditioning	To improve sludge dewatering or thickening rate To improve solids capture To improve compactability Stabilization Pathogen destruction Odor control
Dewatering	Water removal Volume and weight reduction Improved ease of handling by conversion of liquid sludge to damp cake
Heat Drying and High Temperature Processing	Volume and weight reduction Pathogen destruction Solids conversion to ash Recovery of dried sludge for use as soil conditioner Stabilization

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sludge, and can inactivate pathogens through high temperatures and extended detention times (4-11).

- Lime treatment--raising the sludge pH to above 12.0 for 30 minutes by lime addition will suppress putrefaction for several days. Once landfilled, the pH drops and gradual decomposition of the organic matter will occur with reduced odor generation. Lime treatment normally reduces bacterial and viral hazards (25,29), reduces odor to a negligible value, and improves dewaterability (8,9).

- Chlorine oxidation--a proprietary process. Dosages of 500 mg/l of chlorine added to each percent solids concentration of an organic sludge will reduce putrescibility, and eliminate odors and most pathogens (8). There is some breakdown of organic material and formation of carbon dioxide and nitrogen; however, most of the stabilization is effected by substitution or addition of chlorine to the organic compound to form new compounds which are biologically inert.

- Heat treatment--applying heat to untreated or digested sludges can effectively reduce pathogenic organisms present. Heat may be used solely for pathogen reduction as in pasteurization (66°C for ½ hr) or as one step in a process designed to stabilize sludge, improve treatability (heat-conditioning), or reduce mass (e.g., incineration). Pasteurization, a type of heat treatment, can destroy pathogens but does not stabilize the sludge since it does not reduce the volatile solids (30).

- Radiation treatment--the disinfection* of sewage or sludge by beta or gamma radiations. Roughly 10^6 rads (roentgen-adsorptive-dose) are required to assure the inactivation of sludge pathogens (31). Like pasteurization no stabilization is achieved.

Table 3 summarizes the major advantages and disadvantages of the sludge stabilization alternatives. Pasteurization and radiation treatment processes function to merely disinfect sludge;

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* to control the growth of pathogenic microorganisms by destruction or inactivation.

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TABLE 3. ADVANTAGES AND DISADVANTAGES OF MAJOR STABILIZATION ALTERNATIVES (4-11)

Method of Stabilization	Advantages	Disadvantages
Anaerobic digestion	Produces methane Reduces total sludge mass Provides some pathogen inactivation Reduces sludge odor	High capital cost Is susceptible to upsets and system malfunction due to toxic materials in sludge
Aerobic digestion	Easy to operate relative to anaerobic digestion Reduces total sludge mass Provides some pathogen inactivation Substantially reduces sludge odor	High capital costs, though generally lower than anaerobic digestion Produces sludge with poor mechanical dewatering characteristics Have high power costs to supply oxygen
Lime treatment	Low cost and simple Can eliminate odor at pH ≥12.0, though odors can return due to pH decay Inactivates most pathogens Lime treated sludge dewaters easily Lime stabilized sludge does not exhibit septicity during handling and disposal Lime treatment reduces the potential for heavy metal migration from the sludge	No reduction in organic matter occurs Increase in sludge mass
Chlorine oxidation	Improves sand bed dewaterability Reduces sludge odor Chlorinated sludge does not exhibit septicity during handling and disposal	Chlorine-stabilized sludges are of low pH (4.5-6.5) and must be neutralized prior to dewatering or landfilling May lead to formation of toxic chlorinated compounds Does not reduce sludge mass Special safety and handling precautions necessary for chlorine gas gas
Heat treatment (pasteurization)	Pathogens are inactivated or destroyed	Potential for strong odor Does not reduce sludge mass
Radiation treatment	Pathogens are inactivated	Potential for strong odor Does not reduce sludge mass

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thus, they are considered disinfection processes. Because one of the chief functions of stabilization is to reduce sludge pathogen populations, disinfection processes are sometimes grouped together with stabilization processes.

Conditioning--

Besides stabilization, conditioning processes may alter the biological, chemical, or physical properties of sludge to make the separation of water from sludge easier. Certain conditioning processes accomplish more than merely increasing the dewaterability of sludge; they may also alter the sludge chemically, disinfect it, destroy odors, and may destroy a portion of the sludge mass by liquifaction or oxidation in some processes. Conditioning processes include:

- Inorganic chemical conditioning or phosphate removal--addition of ferric chloride, ferrous sulfate, or aluminum sulfate serves primarily as a coagulant. Hydrated lime is usually used in conjunction with metal salts. Both power plant fly ash and sludge incinerator ash have been successfully utilized in conditioning. Where lime is used in conditioning, the pH is normally raised to 10.5 or above to provide a significant degree of disinfection (9). In this case, conditioning also serves to stabilize the sludge. Inorganic conditioning will add metals to the sludge cake. These processes usually promote the formation of a porous, easily dewaterable and fairly non-compressible structure, and substantially increase the total volume of residual.

- Polymer conditioning--organic polymer coagulants, and coagulant aids have largely replaced inorganic chemicals in sludge conditioning in recent years. Whether they are used in powder, pellet, or liquid form, they promote the formation of a structured, easily dewaterable and compactable cake. Addition of polymers increases aggregation and sedimentation of solid particles in two ways. First, long-chained polymer molecules may chemically and/or physically bond themselves to surface of sludge particles. The effect is the formation of bridges between these otherwise discrete particles, resulting in flocculation. Second, the charge carrying polymer may reduce the net electrical repulsive forces at particle surfaces, thus decreasing resistance of the particles to form aggregates. Typical polymer dosage requirements range from 4 to 40 pounds per ton of sludge.

- Heat treatment--as a conditioning process, heat treatment may result in a substantial reduction in sludge volatile solids and an elimination of pathogens. The solids concentration of the cake and thus its dewaterability is nearly double that of the previous two conditioning alternatives.

- Elutriation--the process of washing the alkalinity out of anaerobically digested sludge, which improves settling, dewaterability and compactability. Three common methods are used in elutriation operations. The simplest method is the single-stage which employs a single contact between the solids and the elutriating liquid. Multi-stage co-current contact in one or more basins and multi-stage countercurrent contact between solids and liquid are the other two methods used. Elutriation can be performed as a batch or continuous operation and the wash water may be plant effluent. Ratios of wash water to sludge usually fall within the range of 2:1 or 3:1. The wash water is treated or disposed of along with digester and filter liquid.

Dewatering--

To reduce the potential leachate generation, and improve workability, landfilling of WWTP sludge usually requires that the sludge be dewatered prior to disposal. Dewatering represents a significant sludge volume reduction, increases its solids concentration, and changes its physical form from that of a semi-fluid to that of a damp solid. The supernatant contains a high concentration of soluble organic matter, ammonia or nitrates, and phosphates. An increase in solids concentration from 5 to about 30% results in removal of about 40% of the total nitrogen from the sludge (assuming that up to 50% of the total nitrogen is in the form of NH_4^+) (32). Common dewatering processes include centrifugation, vacuum filtration, pressure filtration, belt filtration, drying beds, and lagoons. Each process is briefly described below and process performance is indicated in Table 4.

- Centrifugation--a sedimentation process in which the solids-liquid separation is enhanced by rotating the liquid at high speeds so as to subject the sludge to increased gravitation forces. The most widely used type of centrifuge is the solid bowl centrifuge which can increase sludge solids to 35% for raw or digested primary wastewater sludge. The dewatering performance for other sludges is listed in Table 4.

TABLE 4. EXPECTED PERFORMANCE OF VARIOUS DEWATERING METHODS* (8,9)

Wastewater Sludge Type	Solid Bowl† Centrifuge	Vacuum† Filter	Pressure† Filter	Belt† Filter	Drying Bed and Sludge Lagoons
		- Solids, % -			
Raw primary (P)	25-36	25-38	45-50	28-44	up to 60
Waste activated (WAS)	8-12	13-20	45-50	16-32	up to 60
P+ WAS	18-25	18-25	45-50	20-35	up to 60
P+ trickling filter (TF)	18-25	23-30	45-60	20-40	up to 60
Anaerobically digested					
P	25-35	25-38	40	26-36	up to 60
WAS	n.d. (no data)	n. d.	34	18-22	up to 60
P + WAS	15-21	14-25	36-50	18-44	up to 60
Aerobically digested					
P + WAS	12-20	16-23	n.d.	12-30	up to 60
Thermally conditioned					
P + WAS	30-40	33-45	60	38-50	up to 60
High lime (pH $\geq$12)	30-50	28-32	50	n. d.	up to 60

* performance varies with feed solids concentration, and sludge properties, and detention times, depending on process used.

† assume chemical conditioning employed where it can improve performance.

- Vacuum filtration--a vacuum filter generally consists of a cylindrical drum which rotates partially submerged in a vat of sludge. A vacuum is applied between the drum neck and filter medium causing liquid passage through the medium and filter cake retention on the medium. The cake of dewatered sludge is removed by a fixed scraper blade.

- Pressure filtration--several types of presses are available, the most common of which consists of verticle plates which are held rigidly in a frame and which are pressed together between a fixed and moving end. Conditioned sludge is pumped into the press and passes through feed holes along the length of the filter. On the face of each individual plate is mounted a filter cloth through which water passes and solids are retained.

- Belt filtration--several types of dewatering devices are represented in this category, including moving screen concentration, belt pressure filters, capillary dewatering systems, and rotary gravity concentrators. In all of these units, the influent mixture of solids and polymers is placed onto a moving porous screen or belt. Dewatering occurs as the sludge moves through a series of rollers which squeeze the sludge to the belt.

- Drying beds--drying beds are generally used for dewatering of well digested sludges. Attempts to air dry raw sludge usually result in odor problems. Sludge drying beds usually consist of perforated or open joint drainage pipe laid within a gravel base and covered with a layer of sand. Drying is accomplished by water drainage and evaporation.

- Sludge lagoons--sludge lagoons are similar to sand beds; however, drying lagoons are not typically provided with an underdrain system as most drying is accomplished by evaporation.

Mechanical dewatering techniques frequently require prior sludge conditioning to provide optimal performance. Drying beds and lagoons, in addition to fulfilling their basic dewatering function, can also dry sludge to a solids concentration of greater than 50 to 60% (9).

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Heat Drying and High Temperature Processing--

Heat drying and high temperature processes provide a major reduction in sludge mass; thus, they are sometimes called sludge reduction processes. High temperature processes differ from pasteurization and heat-conditioning processes by converting the sludge to a relatively inert ash. High temperature processes can reduce the volume and weight of wet sludge cake by approximately 95%, thereby reducing landfilling requirements (8). Although heat drying is not truly a reduction process, it occupies the same relative position in sludge treatment sequences as high temperature processes. Table 5 indicates the major sludge reduction processes. Each of these processes and their major by-products are described below:

- The by-products of incineration, or complete combustion of sludge, are normally a relatively inert ash, carbon dioxide, water, nitrous and sulfur oxides. Table 6 summarizes the content of ash from four treatment plants utilizing incineration for sludge reduction. Silicon, calcium, and aluminum are major components. Because of the high temperatures achieved, it has often been assumed that pathogen destruction is complete on incineration. A review of literature by Ware (33) showed that various bacteria and other heat tolerant organisms may survive incineration. The degree of survival is dependent on the design and operation of each furnace.

TABLE 5. SLUDGE REDUCTION PROCESSES (5)

Reduction Process	Pretreatment Required	Chief By-Products and Usage
Incineration (including power steam generation)	Thickening and Dewatering	Landfill ash
Wet Air Oxidation	Thickening	Landfill ash
Heat Drying	Thickening and Dewatering	Use dried sludge as soil conditioner
Pyrolysis	Thickening	Utilize by-products of gas, carbon, steam Landfill ash

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TABLE 6. PERCENT COMPOSITION OF VARIOUS SLUDGE INCINERATION ASHES (36)

	- Treatment Plant Locations -				
Element	Millcreek	Beckjord	Tahoe	Kansas City	Range
Zinc	0.56	0.10	0.11	0.13	0.10 - 0.56
Cadmium	0.07	0.10	0.10	0.10	0.07 - 0.10
Arsenic	0.33	0.50	0.50	0.50	0.33 - 0.50
Boron	0.26	0.05	0.05	0.18	0.05 - 0.26
Phosphorus	0.33	0.50	2.70	0.50	0.33 - 2.70
Iron	3.33	5.30	0.97	2.65	0.97 - 5.30
Molybdenum	0.03	0.20	0.20	0.20	0.03 - 0.20
Manganese	0.03	0.05	0.05	0.05	0.03 - 0.05
Aluminum	6.99	9.40	0.29	4.6	0.29 - 9.40
Beryllium	0.001	0.001	0.001	0.001	0.001
Copper	0.03	0.07	0.05	0.05	0.03 - 0.07
Silver	0.01	0.01	0.01	0.01	0.01
Nickel	0.07	0.10	0.10	0.10	0.07 - 0.10
Cobalt	0.07	0.10	0.10	0.10	0.07 - 0.10
Lead	0.013	0.20	0.20	0.20	0.013 - 0.20
Chromium	0.23	0.05	0.14	0.10	0.05 - 0.23
Vanadium	0.13	0.20	0.20	0.20	0.13 - 0.20
Barium	0.26	0.01	0.03	0.08	0.01 - 0.26
Strontium	0.01	0.01	0.01	0.01	0.01
Calcium	8.46	1.5	21.13	6.18	1.5 - 21.13
Silicon	22.00	19.17	11.15	26.96	11.15 - 26.96
Magnesium	1.00	0.45	1.30	0.51	0.45 - 1.30
Other	55.57	61.93	60.61	56.59	55.57 - 61.93

- Wet air oxidation involves burning of organic matter in the absence of flame and in the presence of liquid water. A relatively inert, but moist ash is generated. At temperatures and pressures between 175 and 315°C (350-600°F) and 1200 to 1800 psig, wet air oxidation processes should render a sludge sterile (34). Wet air oxidation does not require preliminary dewatering or drying as required by conventional air combustion processes. However, the oxidized ash must be separated from the water by vacuum filtration, centrifugation, or some other solids separation technique.

- Heat (flash) drying is the instantaneous removal of moisture from sludge by introducing them into a hot gas stream. Heat drying is effected at temperatures too low to destroy organic matter. For ordinary domestic wastewater sludges, sludge moisture content may be reduced as low as 5% of the sludge mass. Chemical addition for sludge conditioning or chemicals present in industrial sludges can increase the amount of water retained in the dried product above 5% (8). Sludge bacterial reduction by as much as seven orders of magnitude has been reported (35); however, these sludges should not be considered sterile because if heat dried sludge is rewetted, the moist environment is amenable to regrowth of organisms.

- Pyrolysis is defined as "the destructive distillation, reduction, or thermal cracking and condensation of organic matter under heat and/or pressure in the absence of oxygen" (8). By-products include a combustible residue, condensates (tar and oil) and other higher hydrocarbons and a fuel gas whose major components are hydrogen, carbon monoxide, carbon dioxide, methane, and water vapor. Trace quantities of high molecular weight hydrocarbons may also be present. Survival of pathogens during pyrolysis is not reported in the literature.

In summary, sludge treatment processes can help reduce the environmental and public health risks associated with wastewater sludge, improve its workability, and reduce its volume. The following sections present the physical, chemical, and biological characteristics of WWTP sludge as they relate to sludge landfilling practices.

PHYSICAL CHARACTERISTICS OF WWTP SLUDGE

The moisture content of sludge is a vital parameter in the landfilling of the sludge; excessive residual moisture will complicate handling and hasten the formation of landfill leachates. Water present in sludges has been categorized by Vesilind as follows (10):

- Free-separates from solids by gravitational settling;
- Floc-entrapped by floc particles and can be mechanically removed;
- Capillary-held by surface tension and can be squeezed from the particle interstices; and
- Particle-incorporated into biological substances.

Upon placement in a landfill, sludges not adequately dewatered during sludge treatment are amenable to instantaneous release of water of the free and floc categories. Pressure developed by succeeding lifts and possible thermal conditioning effected by the release of decomposition heat can lead to the release of sludge capillary and particle water.

Particle water as a source of sludge leachate can be more clearly described as follows (37):

> "Particle water is comprised of intracellular liquid and gels. These are not removed by either gravitational and centrifugal forces or pressure applied by conventional dewatering devices unless these preceded by thermal conditioning. Elevated temperatures are reported to degrade the biological gel substances to free water and also lyse the cell wall of the microorganisms to allow the release of internal fluid."

Hence, all categories of water can potentially be released within the landfill environment although at varying rates and extents.

In addition to causing or contributing to sludge leachates, liquid sludges can complicate handling and landfilling operations. Even dewatered sludge has poor engineering properties insofar as it is largely incompressible and has little bearing strength. Sludges of 20-28% solids will not support equipment working the landfill; sludges of 15-20% will not support cover material (28). Therefore, special operational techniques such as trenching or mixing with refuse are utilized for sludge disposal. Such techniques are described in Section 4 of this report.

Another physical characteristic of sludge that is important in landfill operations is its dewaterability or permeability. Permeability can be defined as the discharge velocity through a unit area under a unit hydraulic gradient. Permeability of sludge is an important influence on leachate quantity. Though the literature does not report the permeability of WWTP residuals, specific resistance values shown in Table 7 can be used to indicate relative permeabilities of five commonly encountered sludges. Low specific resistance values are indicative of a sludge which is easily dewatered or highly permeable, and include chemically conditioned or coagulated sludges. Sludges of higher specific resistance are more difficult to dewater and are less permeable than low specific resistance sludges, and include unconditioned raw, digested, and activated sludges.

TABLE 7. SPECIFIC RESISTANCE OF VARIOUS SLUDGES (5)

Type of Sludge	Specific Resistance (sec^2/g)
Raw	$10\text{-}30 \times 10^9$
Raw (coagulated)	$3\text{-}10 \times 10^7$
Digested	$3\text{-}30 \times 10^9$
Digested (coagulated)	$2\text{-}20 \times 10^7$
Activated	$4\text{-}12 \times 10^9$

Addition of WWTP sludge to municipal refuse tends to alter the water retention capacity of the refuse; that is, sludge moisture will be absorbed by refuse, hastening the onset of the landfill field capacity* and leachate formation. Though the findings of the majority of research has supported this phenomenon, several investigators have found evidence to the contrary. Swartzbaugh et al. (38) found that the addition of industrial sludge to refuse, while not influencing the time to reach field capacity, did have the effect of increasing the moisture retained per unit of mass. The moisture retained ranged from approximately 1200 ml/kg (dry) to 1475 ml/kg (dry) and the amount of sludge additions varied correspondingly from 8 kg to 82 kg per refuse cell. This phenomenon was supported by the findings of Stone (39). He found that the highest water absorptivity of codisposal wastes occurred with the thickest sludge, or sludge with the least residual moisture. Further discussion of water retention and leachate generation phenomenon is presented in Section 5.

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* field capacity is the maximum moisture a soil or solid waste can retain in a gravitational field without producing continuous downward percolation.

In summary, sludge moisture and permeability are critical physical characteristics which can have pronounced impact on leachate generation and sludge engineering properties. Sludge moisture has added environmental as well as public health significance, as described in later sections.

CHEMICAL CHARACTERISTICS OF WWTP SLUDGE

Organics

Information on the nature and relative amount of specific species of the major organic fractions in WWTP sludge is still lacking. Their qualitative and quantitative changes during decomposition are also largely unknown (40). Levin (41) reported the solid fraction of WWTP sludge is composed of about 30% biodegradable organics and 35% stable organics. Humus, a relatively stable organic fraction, has been reported to comprise 33 to 45% of raw WWTP sludge (42).

A compilation of the organic fractions for anaerobically digested and raw sludges reported in the literature are presented in Table 1. Undigested sludges are shown to have a relatively higher organic content (50-80%) than that of anaerobically digested sludges (30-60%). Among the various organic fractions, protein, grease and fat, lignin, and cellulose are major classes. For undigested sludge, the major organic fractions are represented by protein and grease and fat. For digested sludge a similar trend is evident; however, the cellulose and grease groups have been reduced in proportion, and lignin shows a larger fraction of the total. With the exception of lignin, the organics are readily biodegradable and will undergo extensive decomposition when landfilled. Cellulosic materials and grease and fat are biodegradable though not at a rapid rate (40).

WWTP sludges may also contain trace amounts of a variety of synthetic organic compounds such as chlorinated pesticides and polychlorinated biphenyls (PCBs). Table 8 lists some of the organochlorine compounds identified in various municipal sludge samples in recent years and their average concentrations. Notice that wastewater treatment plant sludges with industrial contributions can have substantially higher concentrations of specific organic compounds than sludges without industrial contributions. The data also suggests that the compounds are detected more often in sludges with industrial additions than in non-industrial wastewater sludges.

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TABLE 8. TRACE ORGANIC COMPOUNDS IN VARIOUS WWTP SLUDGES

Compound	Range of Average Concentration in Samples with Compound Detected (mg/dry kg)	Total Samples	Samples with Compound Detected	Reference
Aldrin*	16.2 (I)†	1	1	(18)
Arochlor 1254*	1.8 - 4.8 (I)	35	34	(43,44)
Arochlor 1254	1.5 - 3.5	25	8	(43,44)
Chlordane*	2.8 - 19 (I)	40	39	(43,44)
Chlordane	0.6 - 5.5	25	11	(43,44)
Dieldrin*	0.04 - 2.2 (I)	12	12	(17)
Dieldrin	<0.03 - 0.06	2	2	(17)
Hexachlorobenzene*	0.04 - 0.8	10	3	(43,44)
Lindane*	0.6 - 1.0	10	2	(43,44)
PCBs* (non-specific)	0.35 - 23.10 (I)	12	12	(17)
PCBs (non-specific)	<0.01 - 0.79	2	2	(17)

* On EPA list of priority pollutants

† Denotes industrial contributions to wastewater sludge

Several of the synthetic organic compounds are a potential health hazard because of their toxicity to animals and man, slow decomposition rates, and wide distribution in the environment (45). Organochlorine compounds such as those listed in Table 8 may have half-lives* in excess of 10 years in microbiological systems (46). Many have been found to accumulate in animal and human fat and milk (45). Organochlorine pesticide and polyhalogenated biphenyl compounds (e.g., PCBs) are highly toxic to mammalion systems; many of them are carcinogenic, mutagenic, and teratogenic. Many other trace organic compounds have been identified in sewage sludge and are listed in Table 9. The origins and toxic properties of most of these compounds are not well known (45).

TABLE 9 . OTHER TRACE ORGANIC COMPOUNDS IDENTIFIED IN VARIOUS WWTP SLUDGES (45)

Benzo (b) fluoranthene
Benzo (k) fluoranthene
Benzo (g,h,i) perylene
Benzo (a) pyrene
Benzo (e) pyrene
Chloroanile
Chlorobiphenyl
Chrysene
2,4-D
Dibenz (a,j) anthracene
Dichloroanilene
Dichlorobenzene
Dichlorobiphenyl
Dichloronaphthalene
Dioxins
Endosulfan
Endrin
Fluoranthene
Heptachlor
Indeno (1,2,3,c,d) pyrene
Kepone
Lindane (γ-BHC)
Mirex
Pentachlorobiphenyl
Pentachlorophenol
Perylene
2,4,5-T
Tetrachlorobenzene
Tetrachlorobiphenyl
Tetrachloronaphthalene
Trichloroanilene
Trichlorobenzene
Trichlorobiphenyl
Trichlorophenol

Because of their fat-soluble nature, many synthetic organic compounds tend to concentrate in the skimmings at wastewater treatment plants (8). If the skimmings are added to digestors, which is a common practice, the organics can be further concentrated in the final sludge. Isolation of skimmings from other wastewater solids for separate treatment and disposal can reduce this problem.

Nutrients

Nutrients in WWTP sludge include inorganic nitrogen, phosphorus, and sulfur ions. If in limited supply in a natural water body, the introduction of high concentrations of these ions, particularly nitrogen and phosphorus, can lead to accelerated aging of the water system, or eutrophication. From a public health standpoint, injestion of high concentrations of nitrate- or nitrite-nitrogen, under special conditions, may cause illness and even death, as described in Section 6. Thus, sludge nutrients can be considered environmental and public health risks if the sludge is improperly managed.

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* The time required for one-half of the compound to disappear.

Sommers (47) surveyed the chemical composition of sewage sludges from eight states in the midwestern and eastern United States; the concentration of nitrogen species, phosphorus, and sulfur are indicated in Table 10. Sommers found the total N content in sludges quite variable. Median values ranged from 2 to 4%, a large proportion of which was present as NH_4. Nitrate will be absent from "fresh" anaerobically digested sludges but will be formed gradually through nitrification processes.

TABLE 10. CONCENTRATIONS OF TOTAL-N, -P, and -S, and NH_4 and NO_3 IN SEWAGE SLUDGE (FROM SOMMERS (47))

	Sample		Concentration (dry weight basis)		
Component	Type*	Number	Range	Median	Mean
Total N, %	Anaerobic	85	0.5-17.6	4.2	5.0
	Aerobic	38	0.5-7.6	4.8	4.9
	Other	68	<0.1-10.0	1.8	1.9
	All	191	<0.1-17.6	3.3	3.9
NH_4-N, ppm	Anaerobic	67	120-67,600	1,600	9,400
	Aerobic	33	30-11,300	400	950
	Other	3	5-12,500	80	4,200
	All	103	5-67,600	920	6,540
NO_3-N, ppm	Anaerobic	35	2-4,900	79	520
	Aerobic	8	7-830	180	300
	Other	--	--	--	--
	All	43	2-4,900	140	490
Total P, %	Anaerobic	86	0.5-14.3	3.0	3.3
	Aerobic	38	1.1-5.5	2.7	2.9
	Other	65	<0.1-3.3	1.0	1.3
	All	189	<0.1-14.3	2.3	2.5
Total S, %	Anaerobic	19	0.8-1.5	1.1	1.2
	Aerobic	9	0.60-1.1	0.8	0.8
	Other	--	--	--	--
	All	28	0.60-1.5	1.1	1.1

* "Other" sludges include lagooned, primary, tertiary and unspecified sludges. "All" signifies all types of sludges.

Conversely, "fresh" aerobically digested sludges will contain nitrate with median levels less than 200 ppm. The phosphorus concentration in sewage sludge ranges from 1.2 to 3% and is less variable than nitrogen species, owing to its largely inorganic nature. Sommers reports that only 10 to 30% of the total P in anaerobically digested sludges is organic P (48).

The variable levels of nitrogen species in WWTP sludges is in part the result of sludge handling processes. If sludges are dewatered via centrification, vacuum filtration, or filtering beds, the NH_4 and NO_3 content of sludge will be reduced due to the soluble nature of these constituents. However, substantial nitrogen will remain in the sludge following dewatering since 50 to 90% of the total N in liquid sludge may be in organic combinations (47).

The median concentration of sulfur approximates 1% for digested sludges. Additional information of sludge S indicates that some sludges may contain as much as 2% S, of which a significant part may be present as inorganic sulfur species (49).

Major Ions

Major inorganic ions present in WWTP sludge include K, Na, Ca, Mg, Fe and Al. These ions are potential water quality contaminants primarily due to their ability to increase the level of dissolved solids, contribute to water hardness (Ca, Mg, and Fe), and degrade the aesthetic value of water (i.e., color and taste). Table 11 lists typical quantities of each of these ions in sludge, data supplied by Sommers (47). The concentrations of K, Na, Ca, Fe, and Al show considerable variability. Ca, Mg, Fe, and Al may be added to sludges in the form of lime, ferric chloride, alum, etc., to facilitate sludge settling and dewatering. This may in part, account for the variability observed. Data from Furr et al. (17) indicates Ca and Fe levels to range as high as 11.64 and 8.28% (dry weight) in sludge, respectively, where lime and ferric chloride have been added.

Trace Metals

The concentration of trace metals in WWTP sludge has received considerable attention in the recent past due to the possible detrimental effects of metals on crop growth or uptake of metals by crops from land treatment. In a landfill environment, concern is often expressed of the potential for metals to become incorporated in leachates which could eventually pollute ground waters. Because of the organic nature of WWTP sludge, the formation of organometallic complexes may increase the solubility of the metals beyond that which is observed in municipal refuse landfills.

In 1972-73, a comprehensive survey of the concentration of

TABLE 11. PERCENTAGE OF K, Na, Ca, Mg, Fe, AND Al IN SEWAGE SLUDGE (FROM SOMMERS (47))

	Sample		Concentration (dry weight basis)		
Component	Type*	Number	Range	Median	Mean
K	Anaerobic	86	0.02 - 2.64	0.30	0.52
	Aerobic	37	0.08 - 1.10	0.38	0.46
	Other	69	0.02 - 0.87	0.17	0.20
	All	192	0.02 - 2.64	0.30	0.40
Na	Anaerobic	73	0.01 - 2.19	0.73	0.70
	Aerobic	36	0.03 - 3.07	0.77	1.11
	Other	67	0.01 - 0.96	0.11	0.13
	All	176	0.01 - 3.07	0.24	0.57
Ca	Anaerobic	87	1.9 - 20.0	4.9	5.8
	Aerobic	37	0.6 - 13.5	3.0	3.3
	Other	69	0.1 - 25.0	3.4	4.6
	All	193	0.1 - 25.0	3.9	4.9
Mg	Anaerobic	87	0.03- 1.92	0.48	0.58
	Aerobic	37	0.03- 1.10	0.41	0.52
	Other	65	0.03- 1.97	0.43	0.50
	All	189	0.03- 1.97	0.45	0.54
Fe	Anaerobic	96	0.1 - 15.3	1.2	1.6
	Aerobic	38	0.1 - 4.0	1.0	1.1
	Other	31	<0.1 - 4.2	0.1	0.8
	All	165	<0.1 - 15.3	1.1	1.3
Al	Anaerobic	73	0.1 - 13.5	0.5	1.7
	Aerobic	37	0.1 - 2.3	0.4	0.7
	Other	23	0.1 - 2.6	0.1	0.3
	All	133	0.1 - 13.5	0.4	1.2

* "Other" sludges include lagooned, primary, tertiary, and unspecified sludges. "All" signifies data for all types of sludges.

68 elements contained in municipal sewage sludge from 16 American cities was conducted by Furr et al. (17). The trace metal results are presented in Table 12. Though a variety of wastewater and sludge treatment schemes were represented in the study, no distinct trends linking higher sludge metal concentrations to different processes were observable. However, a number of trace metals were notably high in sludges from specific cities. These include cadmium and chromium (Milwaukee), copper and lead (Philadelphia), nickel (Denver, Los Angeles, Miami, Milwaukee, and Philadelphia), and zinc (Los Angeles and Philadelphia). Note that wastewater from each of these cities have characteristically high industrial contributions. Conversely, wastewaters from Cayuga Heights and San Francisco, which were reported to be almost entirely domestic in origin, had relatively low concentrations of trace metals. Although industrial wastewaters can be implicated in trace metal additions to municipal sludge, sludges from largely domestic sources may also be heavily contaminated with trace metals. Klein et al. found that a major portion of copper, cadmium, chromium, nickel and zinc in wastewater can derive from domestic uses (50).

Based on metal extractability with a variety of reagents, it appears that numerous forms of a given metal may occur in sludges (51-54). Exchangeable, sorbed, organic-matter bound, carbonate, and sulfide forms of Cu, Zn, Cd, and Pb are all present, in varying proportions, in anaerobic sewage sludges (55). Extractions with chelating agents, i.e., DTPA or EDTA, have indicated that sludge-borne metals are extracted in varying proportions from different sludges (52,56). Available data suggest that a variety of metal species are present in sludges, that a common metal form does not predominate in different sludges, and that a change in metal speciation may occur after landfilling the sludges (47).

A summary of the effects of anaerobic and aerobic digestion on the trace metal composition of sludges is presented in Table 13. This information is based on a relatively large number of samples from both domestic and industrial sources in the north-central and eastern region of the United States.

In reviewing the chemical characteristics of WWTP sludge, it is clear that sludge can be highly contaminated. Potential environmentally harmful materials in sludge include nitrogen, phosphorous, trace metals, major inorganic ions and certain organic compounds. Industrial wastewater can be a particularly important source of trace metals and synthetic organic compounds.

BIOLOGICAL CHARACTERISTICS OF WWTP SLUDGE

Major sludge microorganisms of health concern may be

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TABLE 12. TRACE METAL CONCENTRATION IN SLUDGE FROM VARIOUS CITIES (17)

Constituent	Analytical method used	Atlanta	Cayuga Hgts.	Chicago	Denver	Houston	Ithaca	Los Angeles
		- Parts per million (dry weight) -						
Antimony (Sb)	NA	14.6	2.6	4.4	3.5	9.9	5.9	14.3
Arsenic* (As)	S	3.6	3.0	29	14	20.4	4.8	26.0
Barium (Ba)	NA	535	272	623	632	485	1004	1066
Beryllium (Be)	ES	<15	<7	<8	<10	<4	<7	<11
Cadmium (Ca)	ASV	106.2	6.8	14.8	46.1	111.8	66.7	171.4
Chromium (Cr)	FAA	1320	189	207	938	3480	840	4925
Cobalt (Co)	NA	9.4	3.9	3.7	8.8	6.3	10.5	18.8
Copper (Cu)	FAA	1483	821	578	1370	1560	1300	2890
Lead (Pb)	ASV	1445	138	605	1011	2238	329	3065
Manganese (Mn)	NA	267	128	95	224	102	527	116
Mercury (Hg)	FL	6.9	10.8	6.1	3.6	3.8	13.6	7.1
Molybdenum (Mo)	NA	6.0	1.2	10.8	18.1	9.8	21	40
Nickel (Ni)	FAA	169	38.4	51.2	562	102	166	402
Selenium* (Se)	F	1.7	1.7	1.7	3.5	---	4.6	8.7
Tin (Sn)	NA	146	128	166	161	234	111	209
Titanium (Ti)	NA	4580	1080	2380	1340	1680	2180	3170
Vanadium (V)	NA	50.4	18.8	48.7	34.1	25.6	14.8	35.7

* environmentally important non-metals (trace elements)

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TABLE 12. (Continued)

- Parts per million (dry weight) -

Constituent	Miami	Milwaukee	New York	Philadelphia	San Francisco	Schenectady	Seattle	Syracuse	Washington, D.C.
Antimony (Sb)	14.8	4.2	10.6	44.4	5.2	9.1	10.8	5.4	10.6
Arsenic* (As)	100	3.3	8.0	16.2	-6.4	21.9	30.0	26.0	6.6
Barium (Ba)	938	344	417	533	542	828	504	322	892
Beryllium (Be)	<5	<4	<12	<7	<5	<15	<17	<13	---
Cadmium (Ca)	149.6	443.7	29.7	192.4	8.5	22.4	64.0	200.0	31.0
Chromium (Cr)	1430	14000	648	2320	1500	458	1320	1000	1260
Cobalt (Co)	17.6	4.3	8.2	15.8	5.3	15.6	9.4	5.1	15.1
Copper (Cu)	1200	1288	1890	2680	900	900	1770	1060	458
Lead (Pb)	1467	2253	1976	7827	2521	598	2411	1412	498
Manganese (Mn)	32	134	152	95	113	235	350	216	323
Mercury (Hg)	15.5	3.4	15.0	4.7	18.0	9.1	8.2	8.4	5.8
Molybdenum (Mo)	37	32.9	5.0	8.1	2.2	25.5	2.3	4.5	3.6
Nickel (Ni)	453	360	140	432	223	72	153	211	---
Selenium* (Se)	2.9	1.7	2.7	3.4	3.0	4.7	2.7	2.1	1.9
Tin (Sn)	289	133	202	492	133	189	373	191	291
Titanium (Ti)	2360	1580	2050	2680	1910	1960	2560	1550	4280
Vanadium (V)	34.8	22.9	53.9	38.4	35.4	38.7	57.3	50.1	91.5

* environmentally important non-metals (trace elements)

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TABLE 13. MEDIAN CONCENTRATIONS OF MAJOR TRACE METALS IN SEWAGE SLUDGE (FROM SOMMERS (47)

	Type of Sludge		
Metal	Anaerobic	Aerobic	All Sludges
	-- mg/kg (dry weight basis) --		
Pb	540	300	500
Zn	1,890	1,800	1,740
Cu	1,000	970	850
Ni	85	31	82
Cd	16	16	16
Cr	1,350	260	890

divided into four broad categories: bacteria, viruses, parasites, and fungi. In considering disease hazards connected with sludge landfilling, a distinction can be made between those pathogens present in sewage sludges and those that might appear during landfilling processes.

Bacteria, viruses, and parasites (including protozoa, helminths, and nematodes) are considered primary pathogens and are incorporated into the sludge during its formation in wastewater processing. These pathogens reflect the type and number of enteric infections experienced by the community served by the sewage system. Many of the agents of enteric infections are excreted in high numbers in the feces of infected individuals, and a few such infected individuals in a community can produce detectable numbers in sewage samples. Therefore, it should be assumed that raw sewage sludge may contain, over a period of time, all enteric organisms that are presented in the sewered population (57). Additional sources of sludge microbes include food wastes, domestic pet feces, industrial wastes from food processing, and biological laboratory wastes.

Fungi are considered secondary sludge pathogens,[*] insofar as they are only numerous in sludge when given the opportunity to grow during some treatment or storage process (8). Fungi spores are ubiquitous in the environment and can utilize sludge as nutrient media to grow new fungal colonies.

Sludge processing practices can diminish the concentrations of pathogenic bacteria, viruses, parasites, and fungi. Anaerobic

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[*] Fungi are also considered secondary pathogens since they are primarily capable of infecting individuals whose health is already stressed by disease.

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sludge digestion, aerobic sludge digestion, lime stabilization, composting, and heat and radiation treatment are among the popular methods of treating waste sludges to diminish the concentrations. A summary of treatment effectiveness of some of these processes in pathogen removal can be found in Table 14.

TABLE 14. MUNICIPAL WASTEWATER TREATMENT PLANT INACTIVATION OF PATHOGENS IN SLUDGES

Lime	Kills pathogenic bacteria and probably viruses at pH 11.5 in ½ hr (25,28), though survival of parasites such as Ascaris noted (25).
Heat--Pasteurization	Destroys all pathogens including parasite ova and cysts, at 70°C for ½ hr (59,60).
Composting	Mechanical: destroys pathogens, except fungi and parasitic ova, at 50°C to 60°C for 7 days (33) Contour: no discernable trends.
Anaerobic digestion	Survival of pathogenic microorganisms (viruses, bacteria, and parasites) at mesophilic temperatures (20-40°C). Survival of viruses at thermophilic temperatures (40-70°C) for up to 60 days (33).
Aerobic digestion	Reduces bacteria to below detectable limits in 24 hr at 60°C (61), though virus and parasites believed capable of survival.
Particle Radiation	Destroys all pathogens at approximately 10^6 rads (31,62).

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Bacteria

Bacteria represent the largest microbiological population in raw municipal sludge, generally ranging from 10^9 to 10^{10} organisms per 100 ml. Unlike viruses, bacteria can reproduce outside the host organism. This is an important factor inasmuch as a disinfected sludge placed in a landfill could attain the same or greater levels of pathogenic bacteria as before sludge treatment through regrowth of the organisms which remain after

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treatment and serve as a seed.

The most important of the pathogenic bacteria found in sludge are listed in Table 15, together with the diseases they cause. *Salmonella*, *Shigella*, and *Vibrio cholera*, comprise the most important groups of bacteria capable of contaminating drinking water and causing disease in man (63). Some bacteria are capable of forming spores which can survive extreme heat, irradiation, toxic chemicals, dehydration, or starvation. The aerobic bacterium *Bacillus* and the aerobic bacterium *Clostridia* are the most common such spore formers.

TABLE 15. SOME PATHOGENIC HUMAN BACTERIA POTENTIALLY IN WASTEWATER SLUDGE AND DISEASES THAT THEY MAY CAUSE (8,32).

Species	Disease
Salmonella arizonae	Arizona infection
Bacillus anthracis	*B. cereus* gastroenteritis; anthrax
Brucella abortus	Brucellosis-Malta or Undulant fever; contagious abortion (in cows)
Vibrio cholerae	Cholera, diarrhea
Clostridium perfringens	C. *perfringens* gastroenteritis; food poisoning
Clostridium tetani	Tetanus
Clostridium botulinum	Food poisoning, often fatal
Corynebacterium diptheriae	Diphtheria
Escherichia coli	Urinary infection, infantile diarrhea
Leptospira sp.	Septicemia (leptospiremia), leptospiruria and kidney infection
Mycobacterium tuberculosis	Tuberculosis
Proteus sp.	Gastroenteritis
Pseudomonas sp.	Colonize burn sites, wounds, and lower respiratory tract; infantile diarrhea; septicemia
Salmonella sp. (over 1,500 serotypes)	Salmonellosis; acute diarrhea and many other diseases
Salmonella paratyphi, A,B,C	Paratyphoid fever
Salmonella typhi	Typhoid fever
Shigella sp.	Shigellosis; bacillary dysentery; acute diarrhea
Yersinia pseudotuberculosis	Pseudo tuberculosis legions in mesenteric glands, also in the intestines and lymph nodes of healthy carrier

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Pathogenic bacterial species can be destroyed during sludge stabilization, disinfection, and dewatering processes. In general, anaerobic digestion (approx, 35°C; 20 day mean residence time) reduces sludge bacterial counts by one to four logs (8); aerobic digestion (approx. 45°C for 24 hr or 60°C for ½ hr) provides similar results (61). Long term storage (6 months at 4°C) of anaerobically digested sludge has shown major reductions in fecal and total coliform and _Salmonella_ bacteria (29). Lime treatment at pH 11.5 and extended detention times (e.g., 24 hr) can also significantly reduce bacteria levels (25). Few data are available on the potential of chlorine for reducing pathogenic organisms in sludge. The EPA reports of one study in which primary sludges with 0.5 to 0.85% solids concentration were treated with 1000 mg/l chlorine, and total and fecal counts were reduced below detection limits (8).

Viruses

Viruses are found in raw sludge in numbers several orders of magnitude lower than bacteria. Raw primary and waste-activated sludges normally contain 10,000 to 100,000 PFU per 100 ml (8). Since viruses do not multiply outside of living susceptible cells, contaminated sludge is a media of transfer of these viruses, not usually a media of growth.

Viruses are not normally found in the intestines of healthy individuals, but enough people are infected at any time to ensure the presence of enteric viruses in community sewage and sludge (64). Many of the viruses that cause disease in man have been identified, or are suspected of being, in sludge. The major virus subtypes transmitted in feces are listed in Table 16 along with the diseases they may cause. The diseases include hepatitus, poliomyelitis, and a variety of other illnesses ranging from ill-defined fevers to meningitis and gastroenteritis.

It is apparent in the literature that digested sludge is not free of enteric viruses. Well operated digesters; however, can substantially reduce virus levels. Moore _et al_. (65). Ward and Ashley (66), and Bertucci _et al_. (67) reported reduction of the concentrations of detectable poliovirus by one to several orders of magnitude, depending on digester detention time, operating temperature, and method of operation.

It has been reported that chlorination (68), heat processes (59,60,69), dessication (29), irradiation (62,70,71), and high pH (29) can destroy viruses. Stern and Farrell (29) suggested that a pH in excess of 11.5 should inactivate known viruses. The investigators also reported almost 50% virus inactivation with sludge storage at 20°C (67°F) for two weeks under laboratory conditions (29). Pathogenic viruses in sludge are effectively destroyed by heat (70°F) at extended detention times (30 min) (69).

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TABLE 16. SOME PATHOGENIC HUMAN VIRUSES POTENTIALLY IN WASTEWATER SLUDGE AND DISEASES THAT THEY MAY CAUSE (8)

Name	Disease
Adenoviruses	Respiratory infection, i.e., colds, bronchitis, croup, pneumonia
Coxsackie virus, Group A	Coxsackie infection; viral meningitis; AFRI*, hand, foot, and mouth disease
Coxsackie virus, Group B	Coxsackie infection, viral meningitis; viral carditis, endemic pleurodynia, AFRI*
Poliovirus (3 types)	Poliomyelitis
Reoviruses	Diarrhea and respiratory diseases. Similar to those noted for adenovirus
Hepatitis virus A	Viral hepatitis
Norwalk agent	Sporadic viral gastroeneritis
Rotavirus	Winter vomiting disease; diarrhea

* AFRI is acute febrile respiratory illness.

Parasites

Potential parasitic disease agents in sludge include protozoa, nematodes, and helminths. Sludge parasites exist primarily in the form of cysts or eggs contributed by the feces or urine of infected individuals or animals. In a study on parasites in sludges in the southern United States, Reimers _et al_. (72) noted a significant increase in _Ascaris_ sp. ova in the sludge from a plant receiving wastes from a swine slaughter house. Other sources could include rendering plants and dairies (73). The ova and resistant stages of parasites found in sewage generally have a specific gravity greater than one and will settle into sludge during primary sedimentation (74,75). Parasites generally number less than a thousand per 100 ml in raw, unstabilized sludge (76). Some pathogenic protozoa, nematodes, and helminths are listed in Table 17, together with the diseases which they cause.

Parasitic ova and cysts are among the hardiest of sludge microorganisms. Many of the conditions which inactivate bacteria and viruses are ineffective for parasites, particularly nematodes and helminths. For although anaerobic digestion processes destroy the cysts of protozoan, helminth ova can survive and should be expected in digested sludge (75). Drying is particularly destructive to the cysts of *Entamoeba histolytica* but has little effect on *Ascaris* ova (76,77). Plant-scale liming of wastewater sludge at Lebanon, Ohio revealed that *Ascaris* ova could survive 24 hr at a pH greater than 11.0 (75). Cyst and ova of parasites are very resistant to chlorine. Heat appears to be the most reliable mechanism for inactivating parasitic pathogens: heating at 70°C (158°F) for 30 min inactivates parasite ova and cysts (59,60).

TABLE 17. SOME PATHOGENIC HUMAN AND ANIMAL PARASITES IN WASTEWATER SLUDGE (8)

Species	Disease
A. Protozoa	
Acanthamoeba sp.	Amoebic meningoencephalitis
Balantidium coli	Balantidiasis, Balantidial dysentery
Dientamoeba fragilis	Dientamoeba infection
Entamoeba histolytica	Amoebiasis; amoebic dysentery
Giardia lamblia	Giardiasis
Isospora bella	Coccidiosis
Naegleria fowleri	Amoebic meningoencephalitis
Toxoplasma gordii	Toxoplasmosis
B. Nematodes	
Ancyclostoma dirodenale	Ancylostomiasis; hookworm disease
Ancyclostoma sp.	Cutaneous larva migrans
Ascaris lumbricoides	Ascariasis; roundworm disease; Ascaris pneumonia
Enterobius vermicularis	Oxyuriasis; pinworm disease
Nector americanus	Necatoriasis; hookworm disease
Strongyloides stercoralis	Strongloidiasis; hookworm disease
Toxocara canis	Dog roundworm disease, visceral larva migrans
Toxocara cati	Cat roundworm disease, visceral larva migrans
Trichusis trichiura	Trichuriasis; whipworm disease
C. Helminths	
Diphyllobothrium latum	Fish tape worm disease
Echinococcus granulosis	Hydated disease
Echinococcus multilocularis	Aleveolar hydatid disease
Hymenolepis diminuta	Rat tapeworm disease
Tymenolepis nana	Dwarf tapeworm disease
Taenia saginata	Taeniasis; beef tapeworm disease
Taenia solium	Cysticercosis; pork tapeworm disease

Fungi

Decomposition of raw WWTP sludge will generate heat, resulting in potential temperatures ideal for the proliferation of fungi such as actinomycetes, murcorales, and in particular Aspergillus sp. Fungi spores are ubiguitous in the environment and are not normally a component of human feces. Pathogenic fungi, listed in Table 18, are most dangerous when the spores are inhaled by people whose health has already been compromised (78,79).

TABLE 18. SOME PATHOGENIC FUNGI POTENTIALLY IN WASTEWATER SLUDGE AND DISEASES THAT THEY MAY CAUSE (8)

Species	Disease
Actinomyces sp.	Actinomycosis
Asperigillus sp.	Aspergillosis; Aspergillus pneumonia otomycosis
Candida albicans	Moniliasis; candidiasis oral thrust

Fungal spores are small enough (2.5-3.0 μm for Aspergillus sp.) to reach alveoli or to gain entrance to paranasal sinuses. The disease varies in severity from an incidental, saphrophytic relationship with the host to a fulminating, fatal infection (80). It is speculated that growth of fungi is somewhat restricted in a landfill environment because of insufficient aeration. Additionally, it is speculated that sludges low in nitrogen and carbohydrates may inhibit fungal growth through starvation, though literature concerning these matters is presently unavailable.

The reviewed literature clearly indicates that many pathogens can survive wastewater and sludge treatment processes. However, not all WWTP residuals possess the same health impairing potential since they possess different numbers and kinds of pathogenic organisms. Table 19 lists the types of WWTP sludges commonly landfilled and their associated major types of microorganisms of health concern. The list represents a best estimate based on the literature reviewed for this study.

SUMMARY

Wastewater treatment processes can yield a variety of residuals of differing physical, chemical, and biological characteristics. Sludge treatment processes can help mitigate the potential environmental and public health impacts associated with sludge and subsequent landfilling operations. With regards to landfilling, the important physical properties of sludges

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TABLE 19. POTENTIAL PATHOGENS ASSOCIATED WITH COMMONLY LANDFILLED SLUDGES

Type of Sludge	Pathogens
Liquid - unstabilized	
Gravity thickened primary (p), secondary (s), combined (c) sludges without chemicals	bacteria (bac), viruses (vir), protozoa (pro), helminths (hel)[#] fungi (fun)[§]
Gravity thickened primary, secondary, or combined sludges with chemicals	bac, vir, pro, hel, fun
Flotation thickened secondary or combined sludges without chemicals	bac, vir, pro, hel, fun
Flotation thickened secondary or combined sludges with chemicals	bac, vir, pro, hel, fun
Liquid - stabilized	
Thickened anaerobically digested primary or combined sludges	bac, vir, hel, fun
Thickened aerobically digested primary or combined sludges	bac, vir, hel, fun
Thickened lime stabilized (pH ≥ 11.5) primary or combined sludges	hel, fun
Thickened chlorine stabilized primary or combined sludges	hel, fun
Thickened heat stabilized (70°C, 30 min) primary or combined sludges	fun
Thickened irradiated (400 kilorads) primary or combined sludges	fun
Dewatered - unstabilized	
Vacuum filtered thermally conditioned[**] primary or combined sludges	fun
Vacuum filtered lime conditioned[‡] primary, secondary, or combined sludges	bac, vir, pro, hel, fun
Centrifuged primary, secondary, or combined sludges	bac, vir, pro, hel, fun
Centrifuged polymer conditioned primary, secondary, or combined sludges	bac, vir, pro, hel, fun
Dewatered - stabilized	
Drying bed, anaerobically digested primary or combined sludges	hel, fun
Drying bed, aerobically digested primary or combined sludges	hel, fun
Drying bed, anaerobically digested and lime stabilized (pH >11.5) primary or combined sludges	hel, fun
Vacuum filtered or centrifuged, anaerobically digested primary or combined sludges	bac, vir, hel, fun
Vacuum filtered or centrifuged, anaerobically digested and lime [‡] or polymer conditioned primary or combined sludges	bac, vir, hel, fun
Vacuum filtered, aerobically digested primary or combined sludges	bac, vir, hel, fun
Centrifuged, heat treated (70°C, 30 min) anaerobically digested primary or combined sludges	fun
Lagooned, anaerobically digested primary or combined sludges	hel, fun
Pressure filtered, anaerobically digested, and lime conditioned[‡] primary or combined sludges	bac, vir, hel, fun
Heat dried	
Heat dried, anaerobically digested sludge	fun
High temperature processed	
Incinerated dewatered primary or combined sludges	bac, hel, fun
Wet air oxidized primary or combined sludges	bac, hel, fun
Special residuals	
Screenings	bac, vir, pro, hel, fun
Grit (unwashed)	bac, vir, pro, hel, fun
Grit (washed and dewatered)	bac, vir, pro, hel, fun
Skimmings (excl. digester skimmings)	bac, vir, pro, hel, fun
Skimmings - digester	bac, vir, hel, fun

[*] primary plus secondary sludge (or preprocessed secondary)

[#] including nematodes (roundworms), and cestodes (tapeworms)

[§] fungi are only numerous in sludge when given the opportunity to grow during treatment or storage processes

[**] thermal conditioning can function as a stabilization process since rendering sludge free of pathogens

[‡] pH ≥ 11.5

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include sludge moisture content and permeability. WWTP sludges can be highly contaminated with persistent organics, nutrients, major ions, and trace metals. Many pathogens can survive wastewater and sludge treatment processes; WWTP sludge can thus represent a significant threat to human health.

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SECTION 4

CURRENT LANDFILLING PRACTICES

INTRODUCTION

The purpose of this section is to introduce current sludge landfilling methods, including design approaches and operational procedures and problems. Also included is a description of the effectiveness of each major landfilling method in protecting the environment and public health.

Burial of WWTP sludge gives rise to a number of major potential environmental and public health impacts, including the formation of contaminated leachate, production of noxious odors, the transmission of disease agents, etc. Each of these major impacts are comprehensively evaluated in Sections 5 and 6, Potential Environmental Impacts and Public Health Impacts, respectively. Landfill design and operational procedures have direct bearing on the impacts associated with sludge burial. These are described in this section.

Disposal approaches for WWTP landfilling have been classified into three major categories (28):

- Sludge-Only Trench
    - --Narrow Trench
    - --Wide Trench

- Sludge-Only Area Fill
    - --Area Fill Mound
    - --Layer Fill
    - --Diked Containment

- Codisposal
    - --Sludge/Refuse Mixture
    - --Sludge/Soil Mixture

While variations of these methods are currently being practiced in the United States, they consist of combinations of these basic methods. Each of the methods are briefly described herein; more thorough and comprehensive descriptions are provided elsewhere (e.g., Process Design Manual-Municipal Sludge Landfills (28)).

SLUDGE-ONLY TRENCH

Disposal of sludge in a sludge-only trench involves the excavation of a trench into which the sludge is placed. The excavated soil is subsequently placed over the sludge as a cover, thereby eliminating the need for substantial soil import. The practice is usually limited to areas in which suitable hydrogeologic conditions exist or in cases where surface application or other alternatives are not viable.

In trench applications, the sludge is usually dumped directly into the trench from haul vehicles (28). On-site equipment is normally used only to excavate trenches and apply cover; equipment does not usually come into contact with the sludge. Cover is normally applied over the sludge the same day it is received, which optimizes odor control.

Sludge-only trenching (also referred to as trench burial) represents a potential despoiling of prime agricultural soils since the nutrient rich top-soil is mixed and buried in a subsoil-surface soil mixture. Another disadvantage is the occassional need for sludge liming prior to placement into the trench. This approach can aid in the immobilization of sludge heavy metals, reduce pathogen levels, and control odors.

Sludge-only trenching methodologies are generally designated as wide trenches (width greater than 3.0 m (10 ft)) or narrow trenches (width less than 3.0 m). Trench dimensions vary widely and are primarily a function of the sites' physical and operational restrictions. Variables affecting depth and length of trenches include the following: depth to bedrock and unfavorable soil conditions, high groundwater table, soil stability, and operational limitations (i.e., site configuration, equipment, and physiographic characteristics).

Narrow Trench

In a narrow trench operation, sludge is placed within the excavation in a single application and the cover soil is applied. This process is illustrated in Figure 1. A cross section of a typical narrow trench operation is depicted in Figure 2.

A major advantage of a narrow trench is its applicability to contain residuals with a wide range of solids content (15-28%) (81). The optimum trench width is governed by a residual's solids content (15-20% solids estimated for 0.6-0.9 m (2-3 ft) trench widths and 20-28% solids for 0.9 to 3.0 m (3-10 ft) trench widths) (28). A narrow trench is capable of handling greater residual moisture due to the effects of soil bridging between the sidewalls. Cover soil applications for a trench width of 0.6-0.9 m (2-3 ft) have been reported to range from 0.6-0.9 m (2-3 ft). Wider trenches of 0.9 to 3.0 m (3-10 ft)

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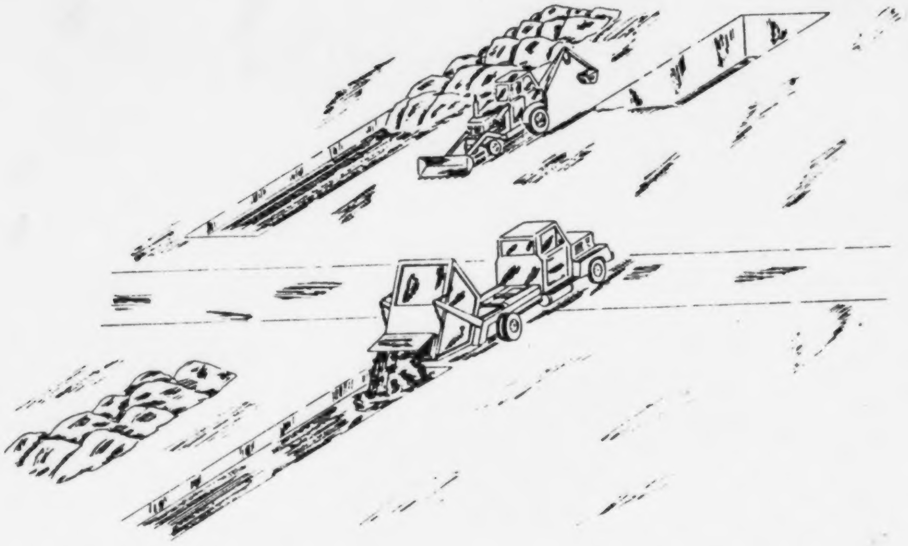
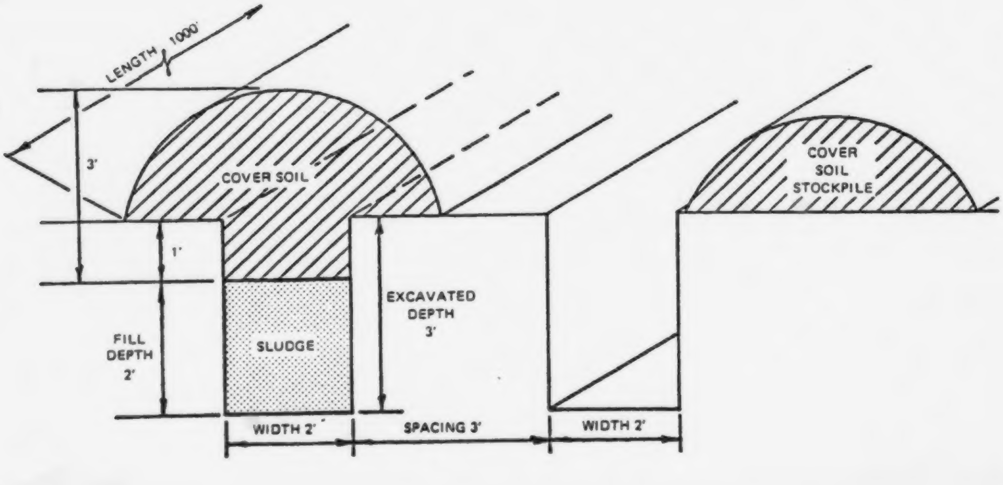


Figure 1. Narrow trench operation (28)


LENGTH 1000'
3'
COVER SOIL
1'
FILL DEPTH 2'
SLUDGE
EXCAVATED DEPTH 3'
WIDTH 2'
SPACING 3'
WIDTH 2'
COVER SOIL STOCKPILE

1' (1 ft) = 0.3m

Figure 2. Cross-section of narrow trench operation (28)

in width require cover soil applications of 0.9 to 1.2 m (3-4 ft) (82).

The main disadvantage of narrow trench operations is its land-intensive nature. Typical sludge application rates in actual fill areas (including inter-trench areas) range from 2,300 to 10,600 m^3/ha (1,200 to 5,600 yd^3/acre) (28). Generally, application rates for narrow trenches are less than for other methods.

The nature of narrow trenching methods suggests that associated environmental and public health risks are relatively minimal. Table 20 lists major environmental and public health impacts connected with sludge landfilling and the effectiveness of narrow trenching methods in controlling these impacts. Narrow trenching methods can be effective in controlling potential leachate generation, vectors, odors, and pose relatively minimal threat to public health. The only potential disadvantages of narrow trenching is blowing dust and noise from operating equipment.

Operational problems with narrow trenching methods are largely unreported in the literature. A landfill in Paris, Maine cited by SCS Engineers (28) encountered problems with sludges of low solids content (14%) not supporting cover material immediately following sludge placement. Thus, sludge was allowed to settle for several days before covering. Since the sludge was stabilized, odor was not a serious problem.

SCS Engineers (28) describe another narrow trench landfill in Montgomery County, Maryland receiving chiefly lime-treated primary and secondary sludge of about 20 to 23% solids. Trenches were 0.6 m (2 ft) wide, 0.9 m (3 ft) deep and varying lengths. The design and operation insured that the sludge was exposed for a minimal time and thus reduced odors, ponding from rainfall, and other undesirable events. Problems encountered with the operation, together with their solution, were the following (28):

- Frozen ground.

  Control: Trenches were constructed during good weather and saved for cold months. Excavated soil was stockpiled for cold weather periods. Soil mounds were insulated with tarpaulin or hay.

- Possible odors near site.

  Control: Lime was placed on spills and masking agents were sprayed from trucks.

TABLE 20. THE EFFECTIVENESS OF NARROW TRENCHING METHODS IN CONTROLLING POTENTIAL ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS

Impact	Effectiveness
Leachate production	Highly effective in minimizing risks of groundwater contamination provided that there is an adequate volume of soil between the sludge trench and water supply to allow for the natural attenuation of harmful leachate components. In uniform soils, most leachate moves vertically downward with negligible movement through the sidewalls of the trenches (83).
Erosion and runoff	Construction and maintenance of surface water runoff control devices (e.g., grass waterways, diversion ditches, rip-rap, sediment basins) are critical for an environmentally sound operation. Improper grading can enhance erosion and runoff; grades of 2 to 5% should be maintained to promote overland surface drainage (84).
Dust	Extensive excavation and stockpiling of soil in narrow trenching operations could enhance blowing dust problems. Soil cover should be vegetated following trench completion. Water can be applied to roads and cover soil to control dust.
Vectors	Vectors are unlikely to present problems at narrow trenching sites provided immediate cover soil application. However, low spots in the fill can form stagnant water bodies for mosquito breeding (28). Continuous grading to fill low spots is essential.
Odors	Odors can be minimized through frequent cover soil application or lime addition. Placing sludge in narrow trenches is more effective in controlling odors in comparison to wide trenches or area fill operations, where greater sludge surface area is exposed.
Noise	Noise impacts from operating equipment and haul vehicles depends on the size of the operation and proximity to populated areas. The number of required operating equipment is similar to wide trench and area fill operations (28).
Aesthetics	Because of the land intensive nature of narrow trenching operations, the working areas may be larger than that necessary in area fill or codisposal operations. The large area required may be unpopular with nearby residents.
Public health	The generation of pathogenic aerosols should be minimal in narrow trenching methods because of limited sludge exposure. Also, since operating equipment usually avoids direct contact with sludge, equipment operators in turn have little opportunity for direct sludge contact. The land intensive nature of narrow trenching can minimize leachate percolation to ground water, though liners are impractical for narrow trenching.

- Mud and dust accumulated on haul vehicles and equipment.

  Control: Mud washing pads were placed at receiving sites to wash equipment during inclement weather.

Wide trench

Wide trench sludge disposal is similar to the narrow trench method but is distinguished by its width (>3.0 m (9 ft)), a higher sludge solids requirement (20% or more), and its capacity for successive sludge lifts. Figure 3 shows a cross section of a wide trench filled with alternate layers of sludge and soil. Typical designs call for placement of two-foot layers of sludge and one-foot intermediate layers of soil (85). The final cover layer of soil is 3 to 5 ft.

A wide trench is often classified according to whether it is a wide trench or a wide trench with dikes, illustrated in Figures 4 and 5, respectively. A wide trench with dikes is usually required when the solids content is less than 32% for containment of the free-flowing liquid. In a wide trench operation, the excavation equipment operates within the fill with sludge placement accomplished either by the transport vehicles entering the trench or unloading from the top of the trench sidewall. Equipment used for cover placement operates either on the solid ground adjacent to the site or by equipment which travels over the sludge, spreading a layer of cover soil. The cover soil is primarily a factor of the sludge solids content, inasmuch as a residual of less than 28% solids is incapable of supporting landfill equipment.

As for narrow trenches, wide trenches may be oriented parallel to one another for operating efficiency. Distances between trenches should be only large enough so as to provide sidewall stability and adequate space for soil stockpiles, operating equipment, and haul vehicles. Soil is often piled on the uphill side of the trench and used to prevent runoff from entering the trench.

Wide trenches with or without dikes are conducive to liner installations which afford greater flexibility in trench depth. Wide trenching also offers greater flexibility in land use and equipment selection.

Wide and narrow trenching methods are dissimilar in regards to their effectiveness in controlling environmental and public health impacts (Table 21). Major differences include the greater potential for leachate generation, vectors, odors, and possible public health impacts for wide trenching methods. Because of the less land-intensive nature of wide trenching

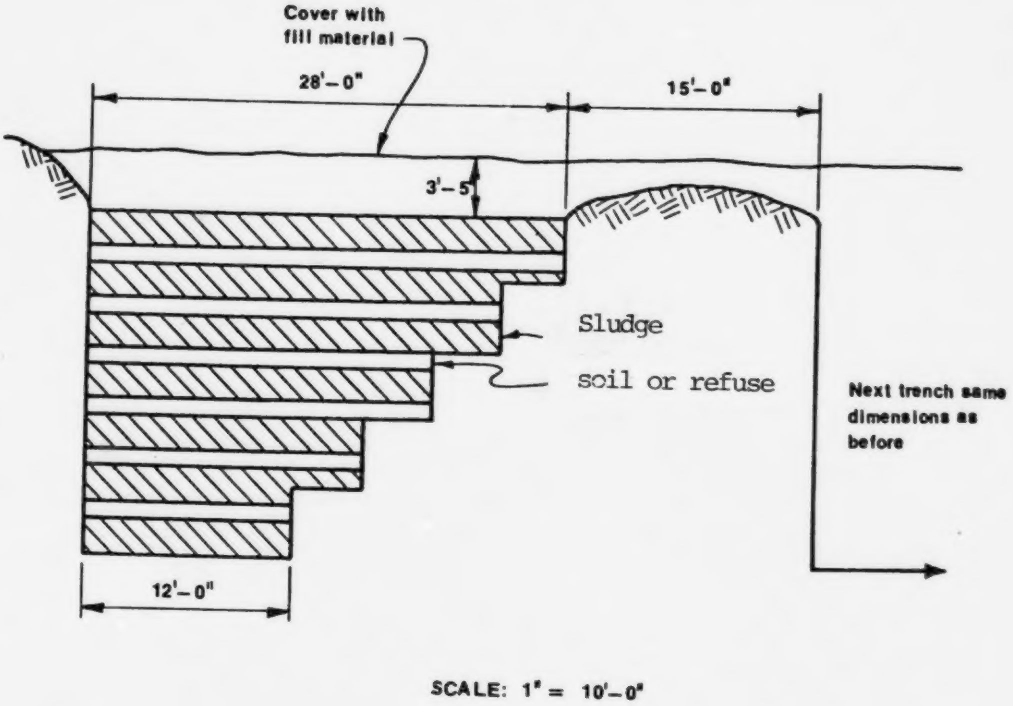

Cover with fill material
28'– 0"
15'– 0"
3'– 5'
Sludge
soil or refuse
Next trench same dimensions as before
12'– 0"
SCALE: 1" = 10'– 0"

Figure 3. Wide landfill trench section (85).

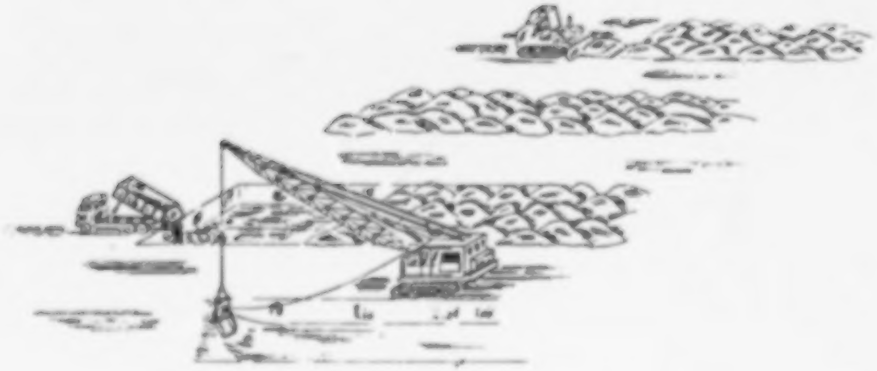


Figure 4. Wide trench operation with dragline (28)

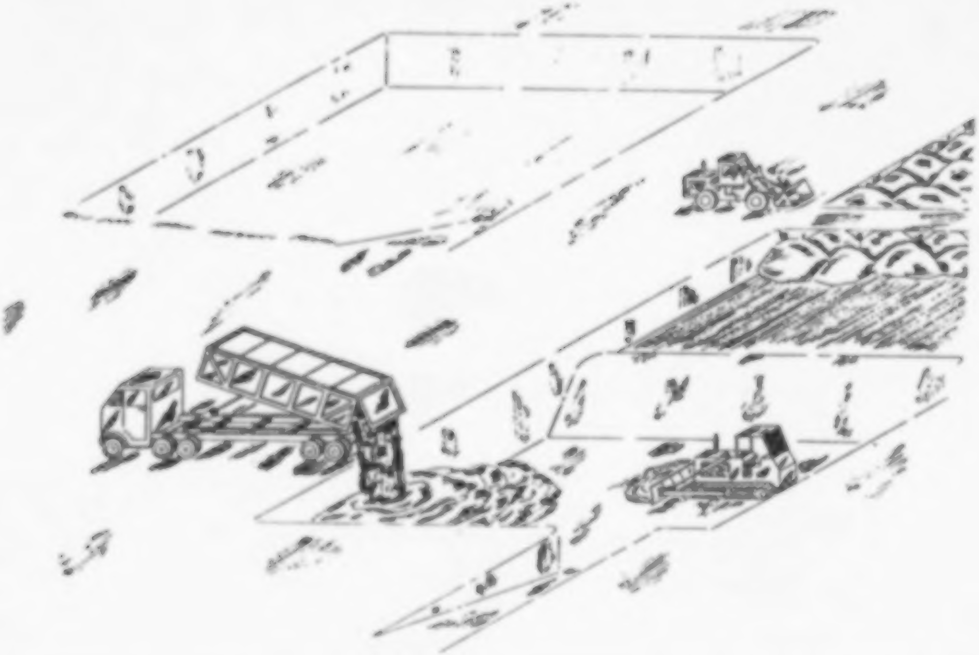


Figure 5. Wide trench operation with interior dikes (28)

TABLE 21. THE EFFECTIVENESS OF WIDE TRENCHING METHODS IN CONTROLLING POTENTIAL ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS

Impact	Effectiveness
Leachate production	Wide trenches are less land-intensive than narrow trenches and can thus release a greater volume of leachate per unit area than narrow trench operations. Their effectiveness in controlling leachate production is, like narrow trenches, a function of soil volume and properties. Weight provided by track 'dozers working atop the sludge may tend to squeeze interstitial water from the sludge mass. Contrary to narrow trenches, liners can be installed in wide trenches to contain sludge moisture and protect ground waters. Low permeability clays or liners can be applied atop finished trenches to prevent infiltration.
Erosion and runoff	Construction and maintenance of surface water runoff control devices (e.g., grass waterways, diversion ditches, rip-rap, etc.) are critical for an environmentally sound operations. Grades of 2 to 5% should be maintained to promote overland surface drainage (84); improper grading can enhance erosion and runoff.
Dust	Blowing dust risks are of similar magnitude to narrow trenching operations. Soil excavations, spreading, and stockpiling can enhance dust problems. Area fill operations appear to pose less risk of blowing dust than trenching operations since soils are usually mixed with sludge for bulking requirements, and area fill operations are less land-intensive.
Vectors	Vector problems are largely correlated with sludge exposure periods. If soil cover is applied carefully and immediately upon sludge placement, vectors are not expected to pose problems. As the fill settles, ponding in depressed areas should be avoided to prevent breeding of vectors.
Odors	Odors can be completely eliminated only if the sludge is odorless. Larger sludge application rates in wide trenches (as opposed to narrow trenches) are amenable to greater odor risks. Frequent soil cover or lining can minimize odors.
Noise	Wide trenching operations generally require 2 to 3 pieces of operating equipment (28), which is comparable to other sludge land-filling operations with similar application rates.
Aesthetics	Trenching operations provide a more favorable appearance than area fill operations since the sludge is disposed of below ground level. Additionally, the less land-intensive nature of wide trenches in comparison to narrow trenches will minimize land required for disposal.
Public health	Exposure of sludge for extended periods can increase the health risks from pathogenic aerosols. Health risks appear comparable to narrow trenching operations.

methods, the potential for downward percolation is increased. Liners can minimize risks of leachate generation. Odors, vectors, and public health impacts are related to sludge exposure periods and larger sludge application rates.

Operational problems and environmental impacts are reported by SCS Engineers at two wide trenching operations - Waukegan, Illinois, and Colorado Springs, Colorado (28). Sludges received at each site were primarily unstabilized, activated sludges of 20 to 25% solids content. Problems encountered during the operation of the landfills together with controls are detailed below (28):

- Freezing temperature made excavation of cells and placement of stockpiled cover impossible.

  Control: During inclement weather, sludge and soil is stockpiled on the site inside a sludge storage building accessible via paved roads. Trench drains in storage building collect sludge moisture.

- Soil runoff from denuded areas.

  Control: Fill areas are seeded with grasses soon after completion. All on-site drainage is channeled through sod-lined ditches to collection ponds.

- Odors from unstabilized sludge during transport, from uncovered sludge in cells during warm weather, from sludge spills, and from equipment.

  Control: Initially sludge transport was to be in dump truck trailers covered with tarpaulins for odor control. However, this caused operational difficulties and transport is not accomplished in open-top trucks. However, after loading, the sludge is covered with a layer of lime for odor control while in transit. In warm weather, sludge in the cells is covered during the day as well as at the end of the day. Lime is sprinkled over any sludge spills. The backhoe bucket (which comes into contact with sludge) is buried in soil at the end of the day to minimize odors.

- Rainfall which collects in the trench caused problems with haul vehicles becoming stuck in the mud. Dust was a problem in dry weather and nearby residents complained regularly.

Control: A layer of fresh dry soil was applied in the pits to improve maneuverability by haul vehicles in wet weather. A water tank truck with a spray bar was used to apply water to on-site dirt roads in dry weather.

- Noise of haul vehicles and equipment, and increased traffic from haul vehicles on public roads.

  Control: Hauling operation confined to hours between 7 a.m. and 4 p.m.

- Mud from site was tracked onto adjoining roadways by haul vehicles.

  Control: A washrack was placed at the sludge processing unit. It is used to clean haul vehicles in wet weather.

- Flies were attracted to and breed in sludge at the site. Nearby residents complained, particularly in warm weather.

  Control: Sludge was sprayed with a disinfectant in the summer to keep the flies down. This disinfectant is the type normally used on livestock to protect them from flies.

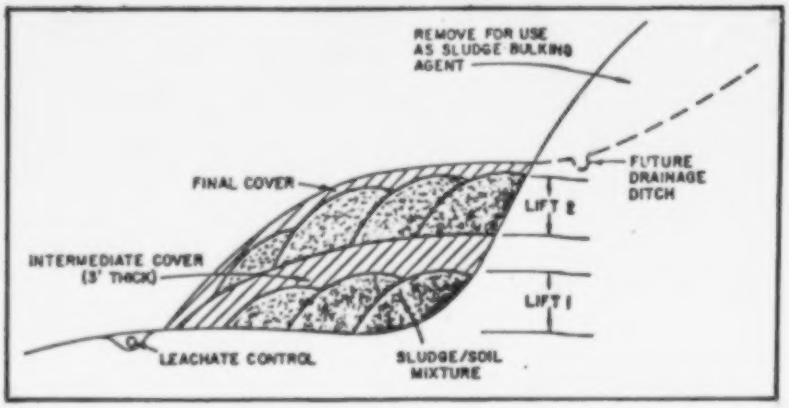
SLUDGE-ONLY AREA FILL

Sludge-only area fill is a method by which sludge is disposed upon the original ground surface. Area fill sludge applications are usually categorized in terms of three methods. These are:

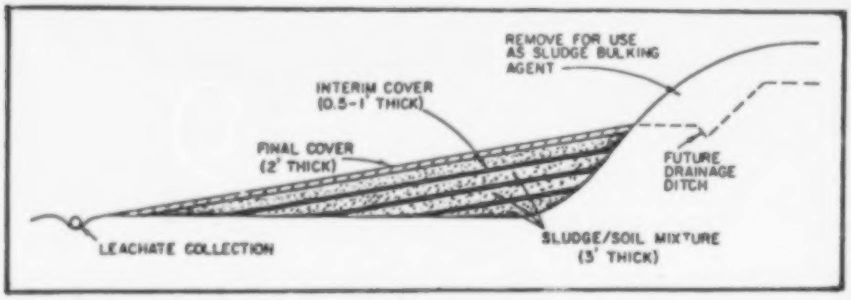
- area fill mound;
- area fill layer; and
- diked containment.

Figure 6 presents cross sections of these three methods.

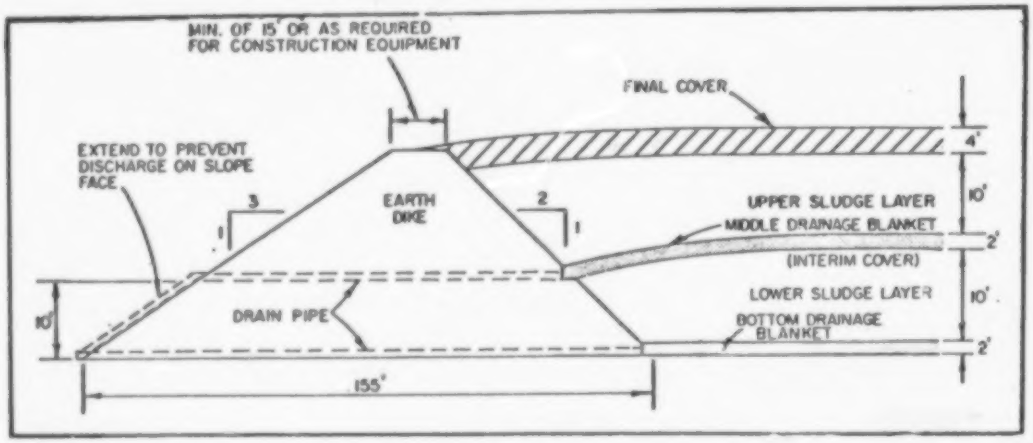
In general, sludge-only area fills require mixing with soil as a bulking agent in order to provide sludge stability. Since sludge-only area fills are usually practiced in locations where a high ground-water table or near-to-surface bedrock conditions prevail, difficulties often arise in obtaining sufficient onsite soils. Cover soil needs place major demands upon onsite or imported soil needs.


REMOVE FOR USE AS SLUDGE BULKING AGENT
FUTURE DRAINAGE DITCH
FINAL COVER
LIFT 2
INTERMEDIATE COVER (3' THICK)
LIFT 1
LEACHATE CONTROL
SLUDGE/SOIL MIXTURE

AREA FILL MOUND


REMOVE FOR USE AS SLUDGE BULKING AGENT
INTERIM COVER (0.5-1' THICK)
FINAL COVER (2' THICK)
FUTURE DRAINAGE DITCH
LEACHATE COLLECTION
SLUDGE/SOIL MIXTURE (3' THICK)

AREA FILL LAYER


MIN. OF 15' OR AS REQUIRED FOR CONSTRUCTION EQUIPMENT
FINAL COVER
4'
EXTEND TO PREVENT DISCHARGE ON SLOPE FACE
3
1
EARTH DIKE
2
1
UPPER SLUDGE LAYER
10'
MIDDLE DRAINAGE BLANKET
2'
(INTERIM COVER)
LOWER SLUDGE LAYER
10'
10'
DRAIN PIPE
BOTTOM DRAINAGE BLANKET
2'
155'

DIKED CONTAINMENT

*1' (1 ft) = 0.3 m

Figure 6. Area fill sludge disposal methods (28)

A common design feature inherent with sludge area fills is the inclusion of surface water drainage control measures. Leachate from the sludge as well as surface runoff from the site require control measures such as runoff diversion ditches and collection systems.

Area Fill Mound

In an area fill mound, sludge/soil mixtures are usually placed in mounds approximately 1.8 m (6 ft) high upon which a soil cover is applied. Figure 6 presents a cross section of this method.

A sludge solids content is usually above 20% in an area fill mound operation due to mixing and handling difficulties with lower solids (28). Soil requirements for bulking purposes are therefore largely proportional to the solids content; mixtures of 0.5 to 1 and 0.5 to 2 (soil to sludge) have been reported (28). Construction of area fill mounds requires that the sludge/soil mixture be relatively stable. Sludge/soil mounds are generally applied in a series of lifts with each lift containing one level of mounds. Light weight operating equipment with swamp pad tracks operate upon area fill mounds.

An advantage of the mound operation is its good land utilization. Whereas trenching operations require inter-trench areas for sidewall stability, soil stockpiles, and operating equipment, area fill mounds can utilize all available space for landfill construction. Successive lifts can also increase sludge application rates. A disadvantage is the maintenance of the mounds, especially during periods of precipitation. For this reason, area fill mounds have high equipment and manpower requirements.

Because area fill mound operations proceed above the ground surface, surface runoff of moisture from the sludge and contaminated rainwater poses a major potential problem (Table 22). Rainfall can also erode the surface of mound operations, exposing the sludge and providing greater risks of vector and odor problems. An abundance of equipment required at an area fill mound operations (28), increases the chances for noise complaints from nearby residents. Public health impacts are a function of the efficiency with which the sludge/soil mixture is covered and prevented from slumping and erosion.

An area fill mound operation in Lewiston-Auburn, Maine (28) receives 40 wet tons (36 Mg) per day of chemically treated sludge. The sludge is mixed with sand (5 parts sludge: 3 parts sand) and the mixture is piled into 6 to 8 ft mounds. During wet weather, the mounds are reported to slump and they must be continually piled and pushed by a small track dozer. The mounds form a lift which is covered by 0.3 to 0.6 m (1 to 2 ft) of

TABLE 22. THE EFFECTIVENESS OF AREA FILL MOUND OPERATIONS IN CONTROLLING POTENTIAL ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS

Impacts	Effectiveness
Leachate production	To achieve an adequate bearing capacity, soil is usually mixed with sludge as a bulking agent. The bulking provides considerable moisture absorptive capacity to retard leachate generation. Because filling proceeds above ground surface, liners are usually installed to protect ground waters. Low permeability covers can inhibit infiltration.
Erosion and runoff	With or without liners, surface runoff of moisture from the sludge and contaminated rainwater should be expected in greater quantities at area fills because of mound construction. Thus, appropriate surface drainage control facilities should be considered. Slumping of area fill mound operations is inevitable (28).
Dust	Large area fill mound operations (e.g., 250 wet tons sludge/day) will require as many as five pieces of heavy equipment to satisfy all areas of operations (28). The extra equipment and activity could increase risks of blowing dust. However, mixing soil with sludge as a bulking agent may reduce potential dust problems.
Vectors	Soil cover of area fill operations is often practiced out of necessity for additional stability when adding lifts (28). Because of time lapses between sludge applications, daily cover is usually not provided. For a putrescible sludge, breeding of flies may be a problem.
Odors	For reasons explained above, daily cover of sludge mounds is sometimes not practiced. In such cases, odors may pose a significant impact provided the sludge is unstabilized or putrescible. Even with daily cover application, slumping sludge mounds may expose sludge and create odors.
Noise	Considering the large equipment requirements for area fill mound operations (see Dust above), noise could be considerably greater than trenching operations.
Aesthetics	Sludge mounds cannot be considered as aesthetically pleasant as trenches because of their inherent visability.
Public health	Limited daily cover practices and erosion or mound slumping create a greater potential threat to public health then trenching operations via aerosolization. If lining is installed, ground- water contamination is unlikely.

gravel to support equipment.

Area Fill Layer

An area fill layer method of sludge disposal consists of a number of sludge layers with separating soil and final cover applications (Figure 6). Sludge is mixed with soil to a consistency which ranges from 0.25 to 1 part soil to each part sludge (28). This mixture is then placed upon either level ground or a gradual slope in applications of 0.15 to 0.3 m (0.5 to 1 ft) with a final soil cover of 0.6 to 1.2 m (2 to 4 ft). In area fill applications, sludge received at the sites are reported as low as 15% solids (28).

As for mounding operations, equipment travels atop sludge in performing mixing, layering, and covering functions. Accordingly, light weight equipment with swamp pad tracks is generally recommended (28). Slopes in layering areas should be relatively flat to prevent sludge from flowing downhill. However, if the sludge solids content is high (e.g., >28%) and/or sufficient bulking agent is utilized, this effect can be prevented and layering performed on mildly sloping terrain.

An advantage of an area fill layer method is the variety of landforms which can be effectively utilized. Operational requirements are usually less for this disposal option since maintenance is less. Disadvantages of this disposal form include poor land utilization (low sludge application rates), large quantities of imported soil, possible slumping, and a high leaching potential. Table 23 indicates the effectiveness of area fill layer methods in controlling potential environmental and public health impacts. Like area fill mounds, slumping and rainwater erosion are foremost concerns because of potential sludge exposure. However, completed area fill layer operations are reported to have greater structural stability (to prevent slumping and erosion) than area fill mound operations (28). Prolonged periods of exposure from erosion, sludge storage, mixing, and placement can promote vector and odor problems, as well as aid in the potential transmission of pathogenic aerosols to man. Subgrade liners are necessary to control potential leachate generation, and low permeability soils or liners atop completed areas will inhibit infiltration to the fill area.

Operational problems at area fill layer sites primarily concern wet weather activity, and operational approaches utilized during these periods. Area fill layering methods are usually suspended during wet weather; sludge is unloaded and left uncovered in flat areas. Provisions are usually made to collect leachates formed during this period. When weather becomes dry, layering operations are resumed.

TABLE 23. THE EFFECTIVENESS OF AREA FILL LAYER METHODS IN CONTROLLING POTENTIAL ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS

Impacts	Effectiveness
Leachate production	Soil bulking agents can provide considerable absorptive capacity for sludge moisture. Liners are usually installed for leachate collection. Upon site completion, low permeability cover soils or liners can help prevent infiltration.
Erosion and runoff	Slopes in layering should be relatively flat to prevent sludge from flowing downhill. However, if the sludge solids content is high and/or sufficient bulking soil is used, a 2 to 5% grade should be maintained to promote overland surface drainage. Completed area fill layer operations are generally more stable than mound operations (28), thus erosion presents less potential problems.
Dust	In general, fewer equipment are required in layer fill methods than other area fill methods (28), consequently blowing dust may be less significant.
Vectors	Soil cover for lift construction may be applied only periodically at some sites, providing exposed sludge and potential vector problems. Strict adherence to sludge soil covering schedules can eliminate vector problems.
Odors	Greater sludge exposure periods inherent in area fill methods promotes odor generation. Lime stabilized sludges can minimize odor potential, as will cover soils added frequently. Because layer fill methods generally offer more stability than mound operations, exposure of sludge due to slumping is less likely to occur.
Noise	Fewer operating equipment required for layer fill methods will reduce noise risks which are generally high for mound operations.
Aesthetics	Aesthetically, little difference is observed for area fill options. Trenching may provide a more pleasant operating and post-closure appearance.
Public health	Lining the area fill layer operation will minimize public health risks from contaminated ground water. Greater sludge exposure periods offer a greater chance for pathogenic aerosolization for unstabilized sludge. Chance of direct contact is increased when equipment works directly with sludge.

Diked Containment

Diked containment is similar to wide trench disposal except that the construction is more complex. Earthen dikes are constructed to create an enclosure above the ground surface (Figures 7 and 8). Diked containment is used only in cases where high ground-water tables, bedrock and/or low solids, preclude use of more conventional methods (28). Large quantities of imported soil may be required for dike construction and bulking since diked containments are often constructed in high ground-water areas.

In diked containment operations, sludge may be either: (1) mixed with soil bulking for subsequent transport and dumping into the containment areas, or (2) dumped directly into the containment area by haul vehicles without bulking soil. As shown in Figure 6, a highly permeable cover is applied to successive lifts which acts as a leachate collection system for sludge moisture from upper lifts. The final cover should be of low permeability to minimize infiltration of moisture to the fill.

The solids content of sludge received at diked containments should be a maximum of 20% (28). For sludges of solids content less than 28%, cover material must be applied by equipment based on solid ground atop the dikes. For sludges with solids content greater than 28%, cover material can be applied by equipment which pushes the soil in place as it proceeds out over the sludge.

An advantage of diked containment is the relatively large sludge application rates and minimum land utilization. A disadvantage is the necessity for subgrade liners and leachate collection systems.

Of the sludge landfilling alternatives, diked containment is perhaps the least effective means of controlling potential environmental and public health impacts because of prolonged sludge exposure during operations (Table 24). Odor and vector risks are great. Public health risks are substantially greater than trenching operations since cover soils are applied infrequently, usually at the end of a working day.

Operational problems for diked containment are not reported in the literature. However, maintenance of dikes would seem to present a continual activity and potential problem.

CODISPOSAL

Codisposal is the practice of depositing sludge at a conventional refuse landfill. Codisposal practices offer significant potential capital and operational cost savings by utilizing the refuse landfill for sludge disposal and its equipment for

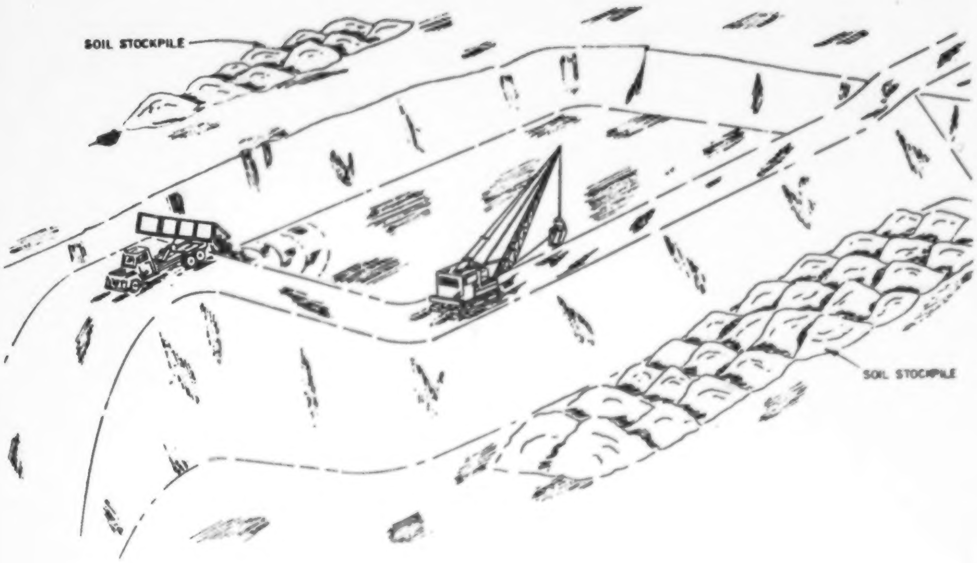

SOIL STOCKPILE
SOIL STOCKPILE

Figure 7. Diked containment operation (28)

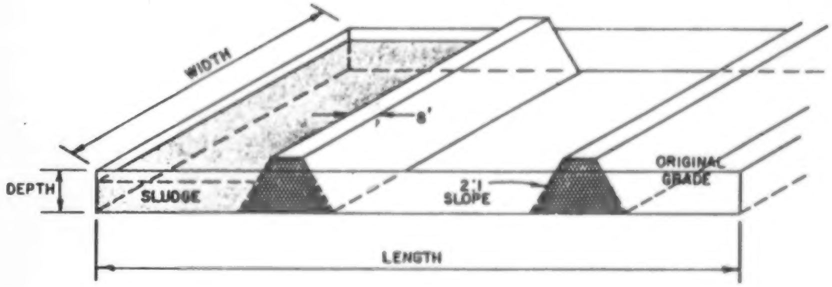

WIDTH
8'
DEPTH
SLUDGE
2:1
SLOPE
ORIGINAL
GRADE
LENGTH

Figure 8. Cross section of diked containment operation (28)

TABLE 24. THE EFFECTIVENESS OF DIKED CONTAINMENT OPERATIONS IN CONTROLLING POTENTIAL ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS.

Impacts	Effectiveness
Leachate production	Usually diked containment methods are conducted without the addition of soil bulking agents. Also, diked containment areas are relatively large and deep. The depth of the fill in conjunction with cover soils places significant surcharge on the sludge. Thus, sludge moisture can be squeezed out and contribute to leachates generated. Liners and other leachate control measures are particularly important in diked containment operations.
Erosion and runoff	The principal source of concern in diking operations is dike failure, which could create significant environmental and public health problems if the sludge is not immediately contained. Control measures including diversion ditches are imperative to control these potential mishaps. Preventing infiltration to containment areas can minimize erosion and/or contaminated runoff.
Dust	Dust problems are highly site-specific. Equipment required for diked containment methods are similar to those required for other trenching and area fill methods (28).
Vectors	Because diked containments are relatively large (15 to 30 m wide, 20 to 60 m long), and sludge application rates are high, exposure of the sludge prior to cover can result in vector problems.
Odor	For reasons mentioned above, exposure of sludge is inevitable in diking operations, and odors can be troublesome. Methods to best alleviate such problems are a high degree of sludge stabilization (aerobic digestion, high lime treatment) or on-site lime addition.
Noise	Noise impacts appear similar to layer fill and trenching operations, based on equipment requirements.
Aesthetics	Provided the diked containment area is out of public view, aesthetics are not unlike other area fill operations.
Public health	Because of lengthy sludge exposure periods, health risks from potential pathogenic aerosols to operating personnel are perhaps greater than trenching methods. Liners are needed to prevent leachate migration.

operations. Conventional codisposal approaches include sludge with refuse mixtures and sludge with soil combinations. Both practices are increasing in use as viable disposal options.

Sludge/Refuse Mixture

The sludge/refuse codisposal operation consists of three basic approaches:

(1) Dewatered or dried sludge is mixed with refuse prior to placement.

(2) Liquid sludge is discharged atop the working face of the refuse.

(3) Dewatered sludge is dumped into a trench, then covered with refuse and soil.

Methods 1 and 2 are the most commonly employed at codisposal sites and are illustrated in Figures 9 and 10, respectively. Although the disposal method used at specific landfill sites may differ slightly from the above methods, it usually consists of a combination of these basic approaches (86).

The sludge/refuse mix ratio is a critical operational specification for codisposal practices. A proper mix ratio ensures that water released from the sludge can be intercepted by the refuse without depleting the refuse adsorption capacity. The mixture would, in this strategy, not attain its full capacity to contain water, thus preventing the release of contaminated leachate. Alternatively, sludge disposal rates which cause the mixture to exceed its field capacity could be utilized where the site has been engineered to intercept the excess drainage for its treatment or disposal. The appropriateness of any one strategy is highly specific to the individual site conditions and sludge and refuse characteristics. These would have to be evaluated on an individual basis.

The Process Design Manual for Municipal Sludge Landfills (28) recommends mix ratios of at least 7 metric tons of refuse to 1 wet metric ton of sludge (approx. 7 tons of refuse to 1 wet ton of sludge) for a sludge of 3% solids content. It states, however, that usually sludges of 20% solids content or more are mixed with refuse in such operations, and that fewer operational and environmental problems may be expected than when a 3% solids sludge is received. At 20% solids content or more, less bulking agent is required and ratios as low as 4 to 1 (refuse/sludge wet wt) are successfully practiced.

In 1978, The Los Angeles County Sanitation District (LACSD) (37) conducted research on refuse absorptive capacities and

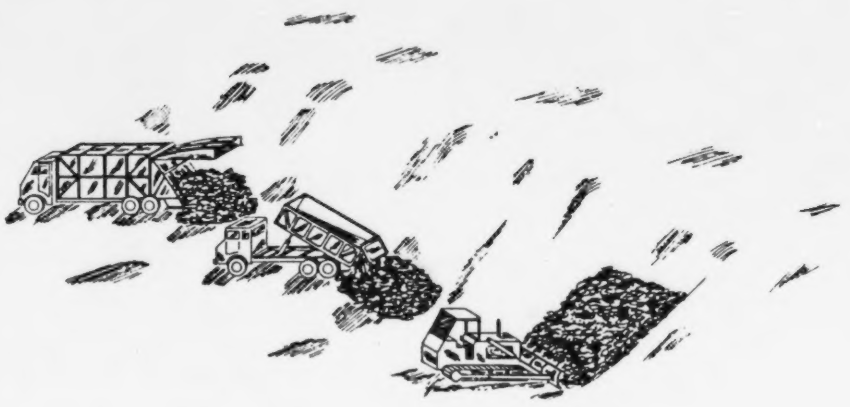


Figure 9. Mixing of sludge and refuse prior to placement (28)

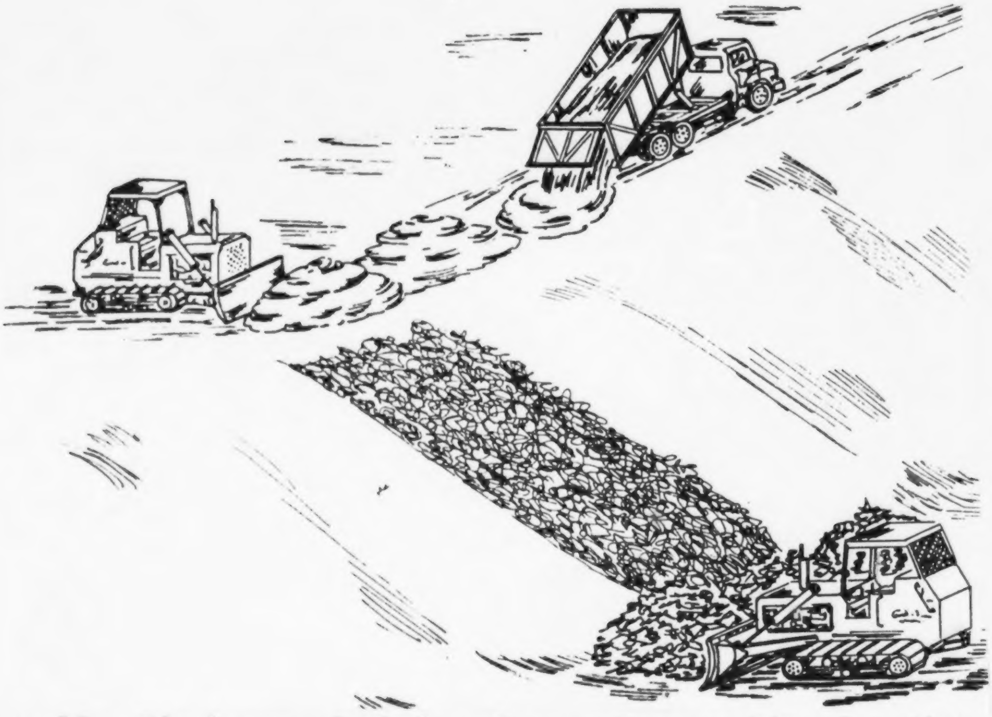


Figure 10. Discharge of sludge along refuse working face (28)

associated sludge/refuse codisposal strategies. The LACSD recognized three major factors governing sludge/refuse mix ratios. These are:

- Sludge solids content (or moisture content);
- Refuse composition; and
- Depth of disposal.

Simulating pressure effects (resulting from the surcharge provided by successive lifts) with special test cells, curves were developed (Figure 11) which show the maximum non-leaching sludge to refuse (wet wt) ratio as a function of sludge solids content at various landfill depths. This relationship is based on the assumption that Los Angeles County type refuse is employed and that the loss of refuse field capacity due to decomposition is 30% at shallow landfill depths and 20% at greater depths. Figure 11 demonstrates a large dependence of the maximum non-leaching sludge to refuse ratios on the depth of disposal mixture. At 25% solids, a sludge cake can be placed at a .93 to 1 ratio (sludge/refuse wet wt) at the 7.5 meter depth, but only a 1 part sludge to 9 parts refuse at the 100 meter depth.

Sludge application rates are generally below those of area fill operations, being comparable to narrow trenching methods (28). However, at higher sludge/refuse mixing ratios, application rates can be increased substantially. Installation of a subgrade liner and leachate collection system might allow increased sludge application rates where ground-water contamination by leachates is a major potential impact.

Table 25 discusses the effectiveness of sludge/refuse codisposal methods in controlling potential environmental and public health impacts. For the most part, the environmental and public health risks posed by codisposal landfills are not unlike conventional sanitary landfills, provided steps are taken to control potential increases in leachate generation. Additional risks posed by vectors and odors at the codisposal site are largely dependent on the sludge characteristics, and can be minimized by sound operational measures such as spot liming and frequent cover soil application. Public health impacts may be slightly increased, though epidemiological evidence is lacking.

Potential operational problems at codisposal sites and control approaches are summarized below (87):

- Sludge/refuse mixture cannot support operational equipment, or equipment experiences slippage when working mixture.

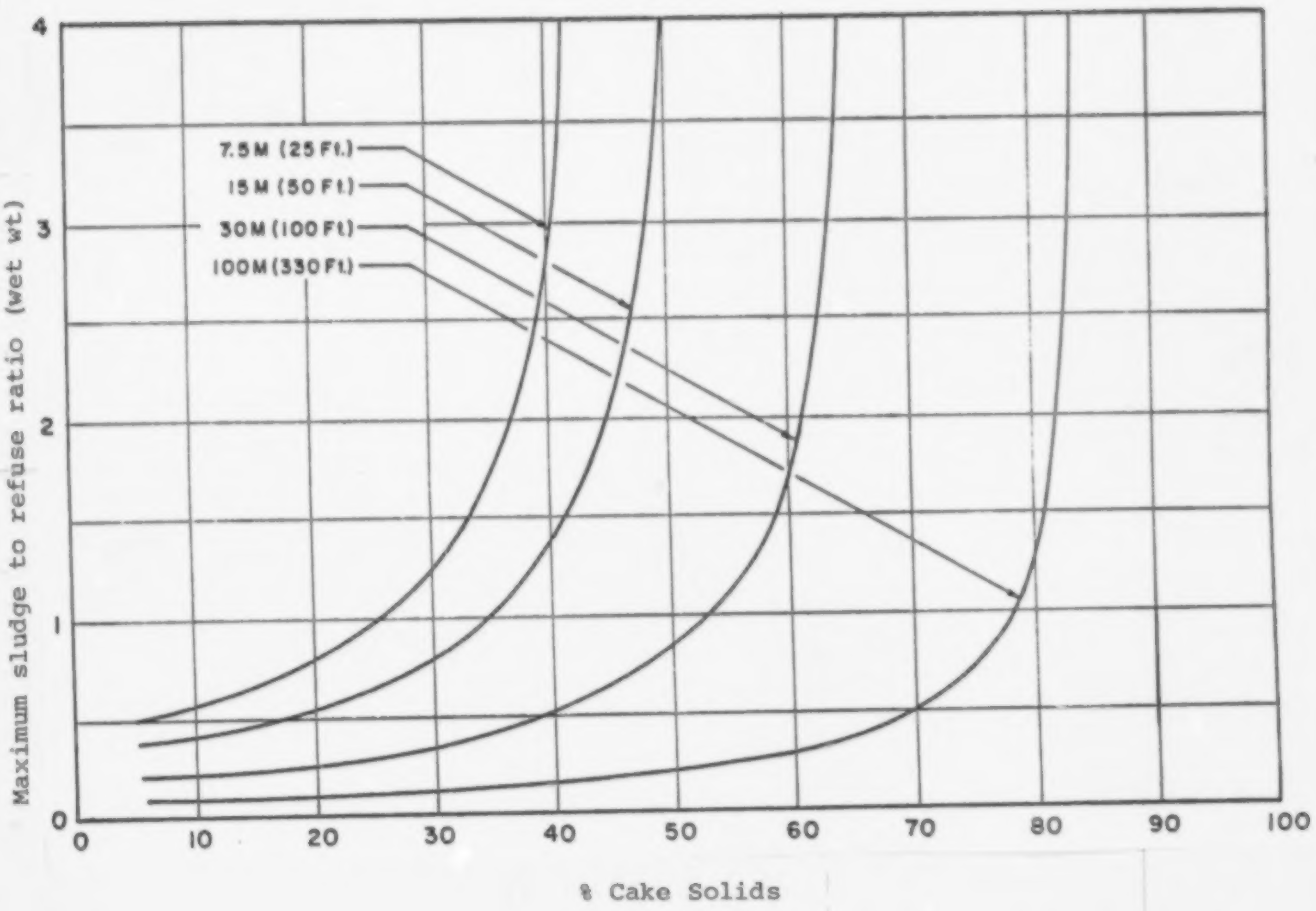


Figure 11. Maximum non-leaching sludge to refuse ratio (37).

TABLE 25. THE EFFECTIVENESS OF SLUDGE/REFUSE CODISPOSAL METHODS IN CONTROLLING POTENTIAL ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS

Impacts	Effectiveness
Leachate production	To the extent that the sludge moisture content does not exceed the absorptive capacity of the refuse, sludge/refuse codisposal methods can be effective in controlling leachate generation. Careful attention to lift heights, sludge moisture control, cover soil permeability, and other design criteria will minimize the risks of leachates increasing beyond that normally encountered at sanitary landfills.
Erosion and runoff	Because sludge and refuse are mixed in specific proportions, delivery of sludge and refuse must be timed correspondingly. Storage of sludge on-site is a potential source of contaminated runoff water. Landfill designs to prevent erosion and runoff problems should include proper grading (2 to 5%) and surface drainage control devices (e.g., diversion ditches, rip-rap, etc.).
Dust	Since daily or weekly trenching excavations and soil bulking are generally not characteristic of sludge/refuse codisposal methods, dust impacts are relatively minimal. Equipment requirements are usually less than for sludge-only area fill operations (28), providing less chance to suspend dust.
Vectors	For putrescible sludge additions to refuse landfills can only enchance vector problems such as flies.
Odor	Odor risks at sludge/refuse codisposal landfill sites are largely related to sludge putrescibility. A sludge with an obnoxious odor could increase odor impact well above that characteristic of a refuse landfill. Cover is normally applied at the end of a working day, allowing considerable opportunity for odor release.
Noise	Operating vehicles are fewer at sludge/refuse landfills in comparison to other sludge disposal options (28), thus reducing noise risk.
Aesthetics	In general, sludge/refuse landfills offer no aesthetic advantages or disadvantages to conventional refuse landfills.
Public health	Provided effective measures to control potential leachate volume increases, threats to ground water and surface water are similar to conventional sanitary landfills. Adding sludge to refuse may increase chances for pathogenic aerosolization, depending on the pathogenic nature of the sludge. Operators of sludge/refuse sites may have increased chances for contracting disease than at conventional refuse landfills, though risks are again related to sludge characteristics.

Control: Increase refuse quantities in sludge/refuse mixtures.

- Sludge/refuse mixture slumps when placed on working face.

  Control: Increase refuse quantities in sludge/refuse mixtures.

- During warm weather, landfill experiences odor problems.

  Control: Apply masking agents.

- Sludge is tracked around the site by equipment or haul vehicle.

  Control: Apply strict control of sludge dumping areas. Place sand and gravel in access roads and place a washing pad in convenient location to wash vehicles.

- Sludge/refuse mixtures slump and become unmanageable during wet weather periods.

  Control: Stockpile sludge in a covered area until wet weather subsides, then apply to refuse at lower sludge/refuse ratios then practiced during dry weather periods.

Operational problems at codisposal sites have included changes in mix ratios required during wet weather conditions and increased traffic during operations (86). Additional problems could include equipment slipping or becoming stuck in sludge, or sludge being tracked around the site by equipment or haul vehicles.

Sludge/Soil Mixture

In a sludge/soil operation, sludge is mixed with soil and the mixture is applied as a cover for areas of a refuse landfill. In this operation, the sludge is disked or mixed into indigenous soil and later retrieved for use as an intermediate or final cover (28). Though not strictly a sludge landfilling method since the sludge is not buried, it is a viable disposal method. Advantages of employing sludge/soil mixtures are: (1) it removes sludge from the working face of a landfill where it may cause operational problems, and (2) vegetation is promoted in completed fill areas and a corresponding savings in fertilizer can be realized. Disadvantages are that greater manpower and equipment are required, and if the sludge is not completely buried, odor may be more severe than for

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sludge/refuse mixtures.

Table 26 indicates that sludge/soil mixtures may promote an increase in environmental and public health impacts. Applied as a cover soil, the mixture may result in a highly contaminated surface runoff requiring some degree of treatment. Vector and odor risks are significantly increased when implementing sludge/soil mixtures as a final cover. Of course, the extent of the risk is largely dependent on the stability of the sludge received. Noise impacts will be increased due to increased equipment requirements. Aesthetics may be compromised due to changes in soil color. Finally, potential public health impacts may be increased by wildlife attracted to completed sites acting as carriers of disease, and by site operators and the general public coming in contact with completed areas.

SLUDGE-ONLY VS. CODISPOSAL LANDFILLING: ADVANTAGES AND DISADVANTAGES

Sludge/refuse codisposal landfilling methods are viewed favorably when compared with sludge-only alternatives for a variety of reasons, some of which were previously mentioned. The advantages of using an existing refuse landfill for sludge disposal in lieu of developing a new sludge-only landfill include (28,87):

(1) Less cost. Capital costs, including land and equipment, will probably be substantially less for codisposal alternatives when compared to a sludge-only landfill. A new site calls for the acquisition of land and equipment, not to mention environmental impact reports and site preparation costs. Sludge addition to a refuse landfill will reduce the lifetime of the site and may require purchase of additional land and equipment to expand the operation; however, expansion costs will probably be minimal in comparison with new site development.

(2) Shorter time delay. A substantial and growing number of states and local statutes require permits for dump or landfill sites (15). Obtaining a permit to dispose sludge at a new sludge-only site may require coordination of several agencies to identify all of the legal, institutional, and environmental ramifications of the permit. Thus, time delays are inevitable. Conversely, processing of a permit to dispose sludge at an existing refuse landfill will probably be quicker, possibly requiring only an amendment to an existing permit.

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TABLE 26. THE EFFECTIVENESS OF SLUDGE/SOIL MIXTURES IN CONTROLLING POTENTIAL ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS

Impacts	Effectiveness
Leachate production	Since applied as a cover soil, sludge/refuse mixtures may help or hinder the generation of leachate depending on the mixture's permeability. A highly impermeable mixture could inhibit rainwater infiltration.
Erosion and runoff	Sludge/soil mixtures used as landfill cover soils are amenable to the formation of highly contaminated runoff which requires interception and possible treatment. The sludge/soil mixture may be beneficial in providing added stability as a cover material, i.e., less amenable to erosion.
Dust	Moisture furnished by sludge in sludge/soil mixtures would help control dust in the landfill area.
Vectors	Potential for vectors, particularly flies, may be increased for the sludge/soil cover strategy in comparison to non-sludge covers. Proper grading must be maintained to prevent ponding of rainwater and mosquito breeding.
Odors	Odors may be increased above levels encountered at refuse landfills depending on the degree to which the sludge is stabilized.
Noise	Implementing a sludge/soil cover scheme for a refuse landfill will require additional equipment and thus the potential for increased noise levels.
Aesthetics	Using sludge/soil mixtures as cover soil may produce an undesirable appearance at a landfill site, particularly if light colored soils are indigenous to an area.
Public health	Public health risks may be increased at a refuse landfill when utilizing a sludge/soil cover material, particularly to site operators and the general public (if allowed access to the site) who come in direct contact with the mixture in completed areas. Runoff must be carefully managed to prevent its entrance to water bodies.

(3) Less public opposition. Establishment of a new landfill site often meets considerable public opposition (88). The public is less likely to resist expansion in the operations of one site then it is to resist the opening of a new site.

(4) More effective land utilization. By utilizing existing landfills for sludge disposal, additional land need not be permanently altered for sludge disposal.

Several potential disadvantages are created through sludge disposal at existing refuse landfill sites. These are (28):

(1) Odors may be increased at the site receiving the sludge, depending on the degree of sludge stabilization.

(2) Leachate may be generated sooner or in greater quantities, resulting in greater potential environmental or public health impacts.

(3) Leachate collection and treatment systems may have to be installed (if not existing) or enlarged (if existing) to handle any additional leachate generated.

(4) Public health risks may be increased for site personnel and/or the general public (if allowed access to the working face), depending on the degree of sludge stabilization.

(5) Changes in landfill operations will be necessary, such as coordination of refuse and sludge deliveries to the site, and controlled dumping of refuse and sludge to maximize moisture absorption and workability.

(6) Operational problems may develop such as equipment slippage or tracking of sludge around the site.

With regard to potential environmental and public health risk, SCS Engineers (28) suggest that the risk should be less for sludge/refuse codisposal operations in comparison with sludge-only alternatives, reasoning that a single disposal site will have less impact then two separate disposal sites. However, the environmental/public health risks of landfills are highly site specific. If the waste is distributed among two separate sites and one fails, there is still one sound disposal site remaining. Conversely, if the waste is placed entirely at one site which fails, the impact can be much more severe since all of the waste is located at this site.

SUMMARY

The design and operation of sludge landfills have been described, along with an evaluation of the effectiveness in which each landfilling method controls potential environmental and public health impacts. Operational problems reported in the literature were identified. Table 27 presents a summary of the various design and operational criteria reported and compares potential environmental and public health impacts for each landfilling method.

TABLE 27. OPERATING CRITERIA AND PERFORMANCE OF SLUDGE LANDFILLING PRACTICES

Current Sludge Landfilling Practices		Land Required (28)	Soil Bulking Agent Required (28)	Sludge Solids Content Recommended (%) (28)	Relative Effectiveness in Controlling Environmental Factors							Leachate Control Measures Required	Potential Public Health Impacts	Potential For Future Land Use at Disposal Site
					Leachate Generation	Erosion and Runoff	Odors	Vectors	Noise	Dust	Aesthetics			
Sludge Only	● Sludge Only Trench													
	Narrow Trench	H	no	≥ 15	H	H	H	H	M	L	H	L	L	M
	Wide Trench	M-L	no	≥ 20	L	H	L	L	H	L	M	H	M	L
	● Sludge Only Area Fill													
	Area Fill Mound	M-L	yes	≥ 20	H*	L	L	L	L	M	L	M	M	L
	Layer Fill	H	yes	≥ 15	H*	L	L	L	L	M	L	M	M	L
	Diked Containment	L	no	≥ 20	H*	L	L	L	L	M	L	H	M	L
Codisposal	● Sludge Spread With Refuse, Covered With Soil	H	no	≥ 3	M	M	M	M	M	M	M	M	M	M
	● Trench, Covered With Refuse and Soil	H	no	≥ 3	M	M	M	M	M	M	M	M	M	M
	● Sludge Dumped on Refuse Covered With Soil	H	no	≥ 3	M	M	M	M	M	M	M	M	M	M
	● Sludged Dried in Piles, Spread With Refuse, Covered With Soil	H	no	≥ 3	L	L	L	L	M	M	L	M	M	M
	● Sludge Mixed With Soil, and Applied To Refuse	H	yes	≥ 20	L	L	L	L	L	H	L	M	M	M

Key: H - High (Comparatively)
M - Moderate "
L - Low "

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[*] provided subgrade liner installation

SECTION 5

POTENTIAL ENVIRONMENTAL IMPACTS

INTRODUCTION

Landfilling of WWTP sludge presents an assortment of potential environmental problems, including pollution of underlying ground water or surface waters, production of odors, and spoiling of land necessary for landfill construction. This section evaluates the potential impacts on water, air, and land quality resulting from sludge landfilling.

IMPACTS ON WATER QUALITY

Because of the toxic and pathogenic nature of many WWTP residuals, their placement into a landfill may lead to the formation of highly contaminated leachates or surface runoff which could migrate from the landfill site. The presence of sludge contaminants in leachate and surface water runoff is a source of environmental concern since the contaminants could eventually enter ground-water and surface water resources. The following discussion reviews existing and peripherally related literature pertinent to the composition and volume of leachates and runoff generated by WWTP sludges, factors influencing leachate composition and volume, and potential environmental impacts.

Leachate Composition

The composition of leachates generated in sludge landfills is governed by several factors including the composition and age of the sludge, sludge moisture levels and the amount of leaching fluid applied, the amount of leachate contaminants precipitated in soil or dissolved from soil, and, in the case of sludge/refuse codisposal, refuse composition and age, disposal methods, and sludge/refuse mix ratios. The interaction of these factors creates a complex and dynamic system. The following discussion of leachate composition is divided into two parts. The first part assesses the potential water quality impacts of sludge landfills by comparing leachate composition data from sludge-only and sludge/refuse codisposal landfills with various water quality criteria. Part two evaluates the influence of sludge type, sludge disposal methods, sludge/refuse mix ratio, and sludge age on leachate composition.

Potential Water Quality Impacts: Leachate Concentration Ranges and Applicable Criteria--

Figure 12 presents the concentration ranges of several chemical and biological constituents of leachates produced from landfilling of: (1) WWTP sludge, (2) municipal refuse, and (3) an admixture of municipal refuse and WWTP sludge. Represented leachate constituents fall within the following major groups:

- General organic indicators (COD, BOD, TOC);
- Total solids and total dissolved solids (TS, TDS, specific conductivity);
- Nutrients (total phosphorus, nitrate-nitrogen, ammonia-nitrogen);
- Major ions (Cl, Ca, Mg, Fe);
- Trace metals (Zn, Cu, Cd, Pb, Ni);
- Pathogens (fecal coliform, fecal streptococci; and
- pH.

A complete list of the concentration ranges of the chemical and biological constituents in leachates from each of the above-mentioned landfill types is provided in Appendix A.

Figure 12 represents an accumulation of data from eight studies (37,39,89-94) on the composition of leachates from WWTP sludge landfills, and numerous refuse landfill investigations. Represented types of sludges include raw primary, activated sludge, chemically conditioned, digested, and septic tank pumpings. All landfill sites were considered active or had been closed less than two years prior to leachate collection. Data from several field test cells are also included.

The impact of sludge landfill leachates upon water quality can be assessed by comparing the concentrations of constituents in leachates to various water quality criteria. The criteria for the following five categories are applicable for estimating the potential impact of sludge landfill leachates:

- Public water supply;
- Fresh water (aquatic life);
- Agriculture water (irrigation);
- Ground water; and

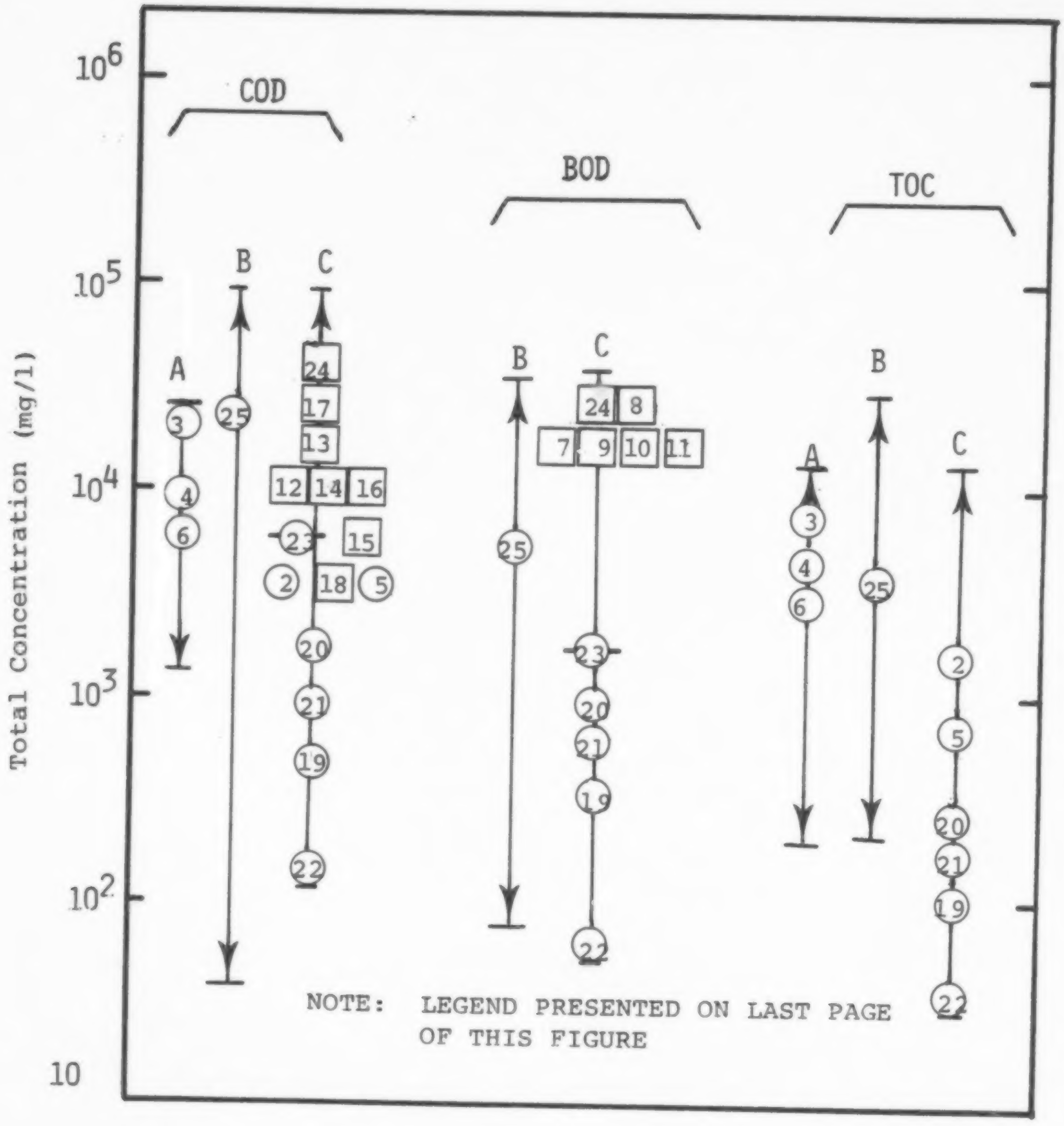
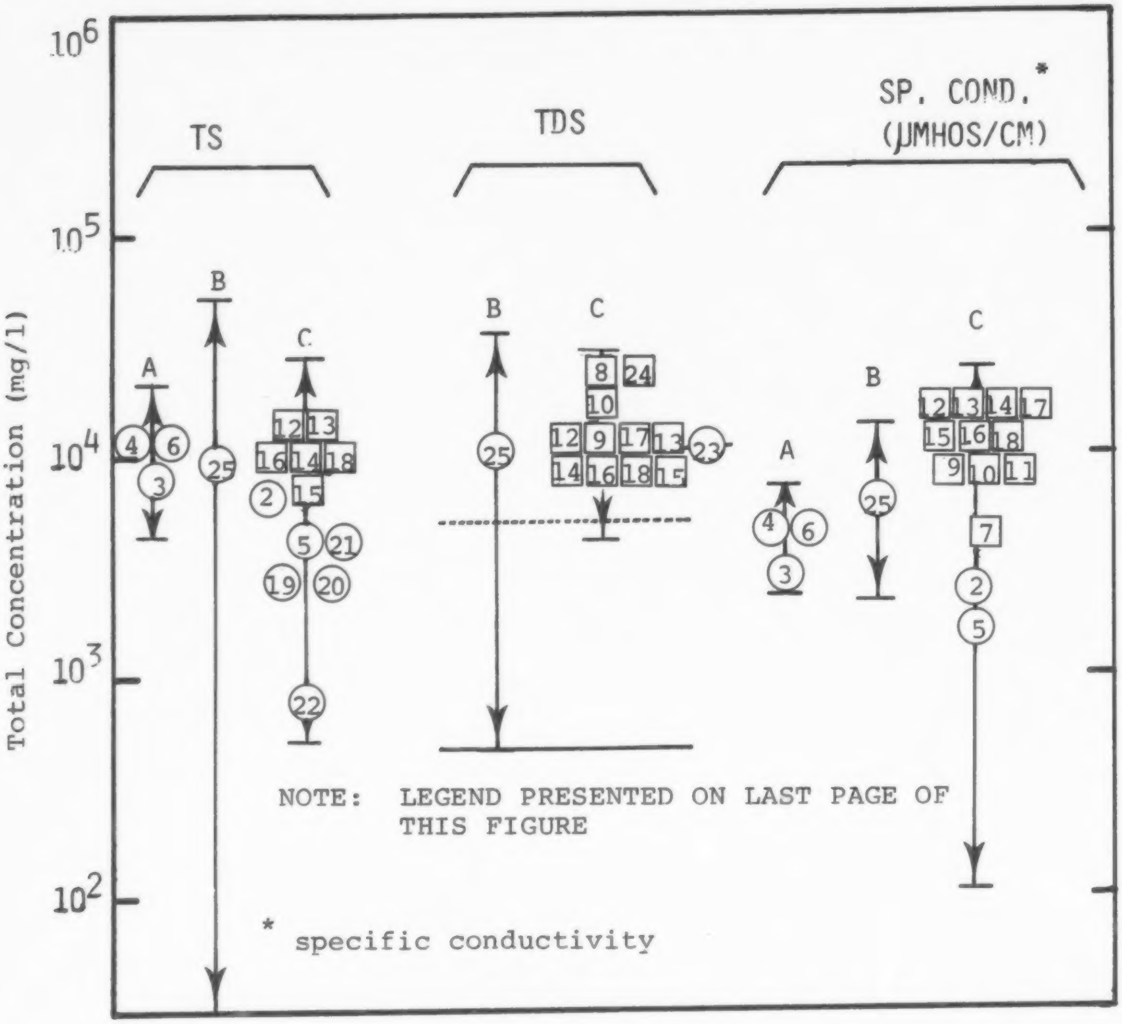


Figure 12. Comparison of leachates from sludge only, sludge/refuse, and municipal refuse landfills.



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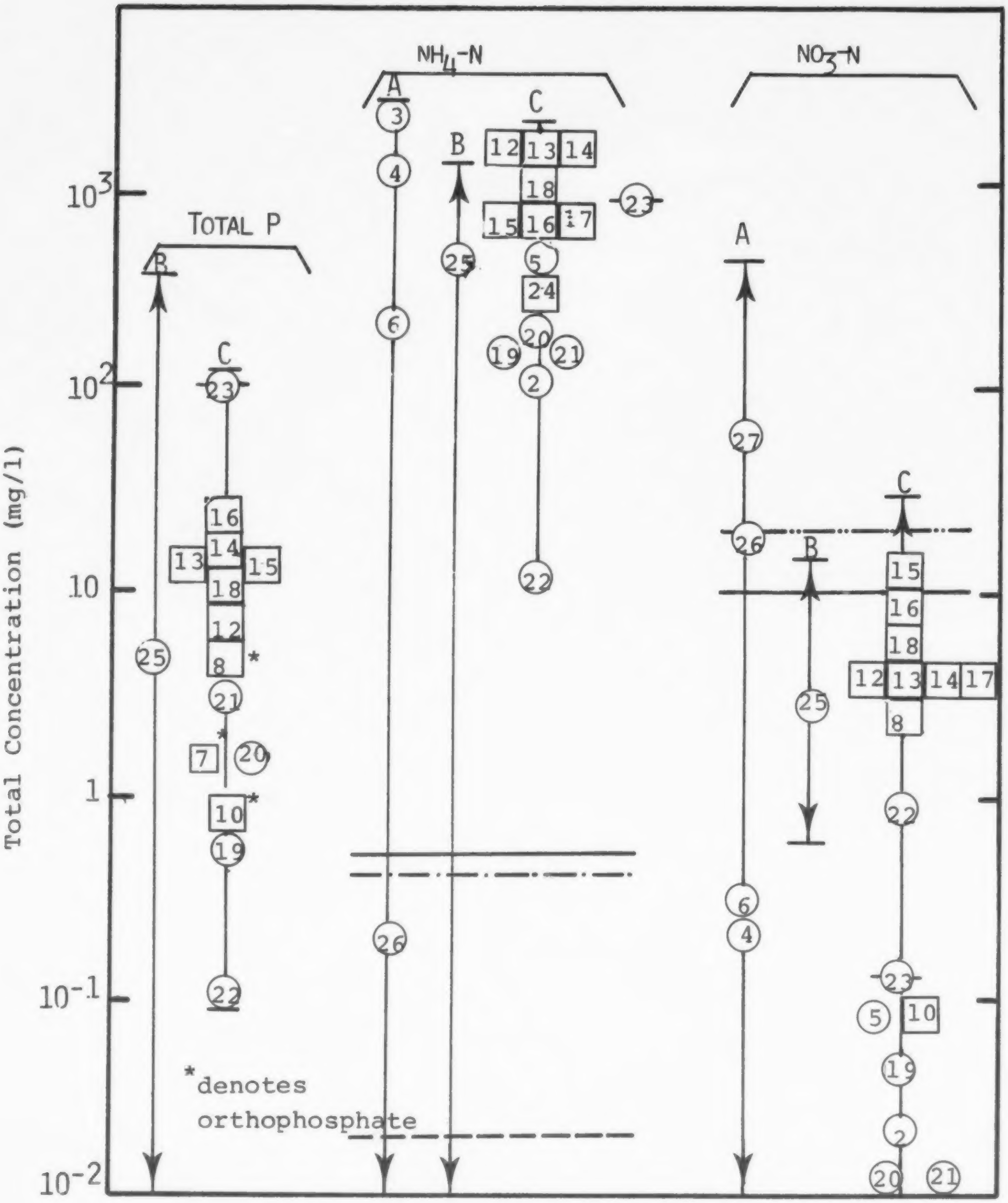
* specific conductivity

Figure 12 (Continued)



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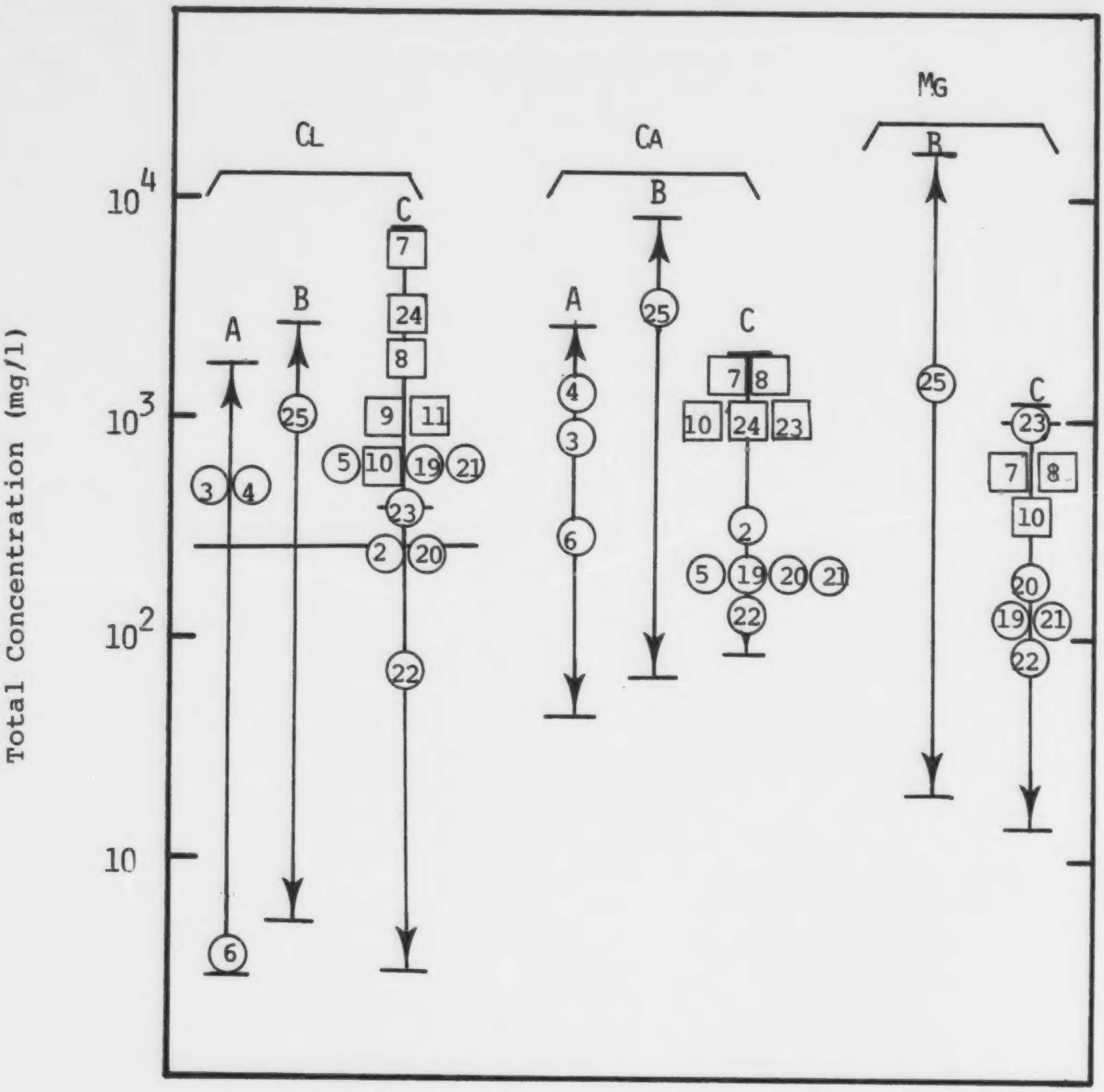

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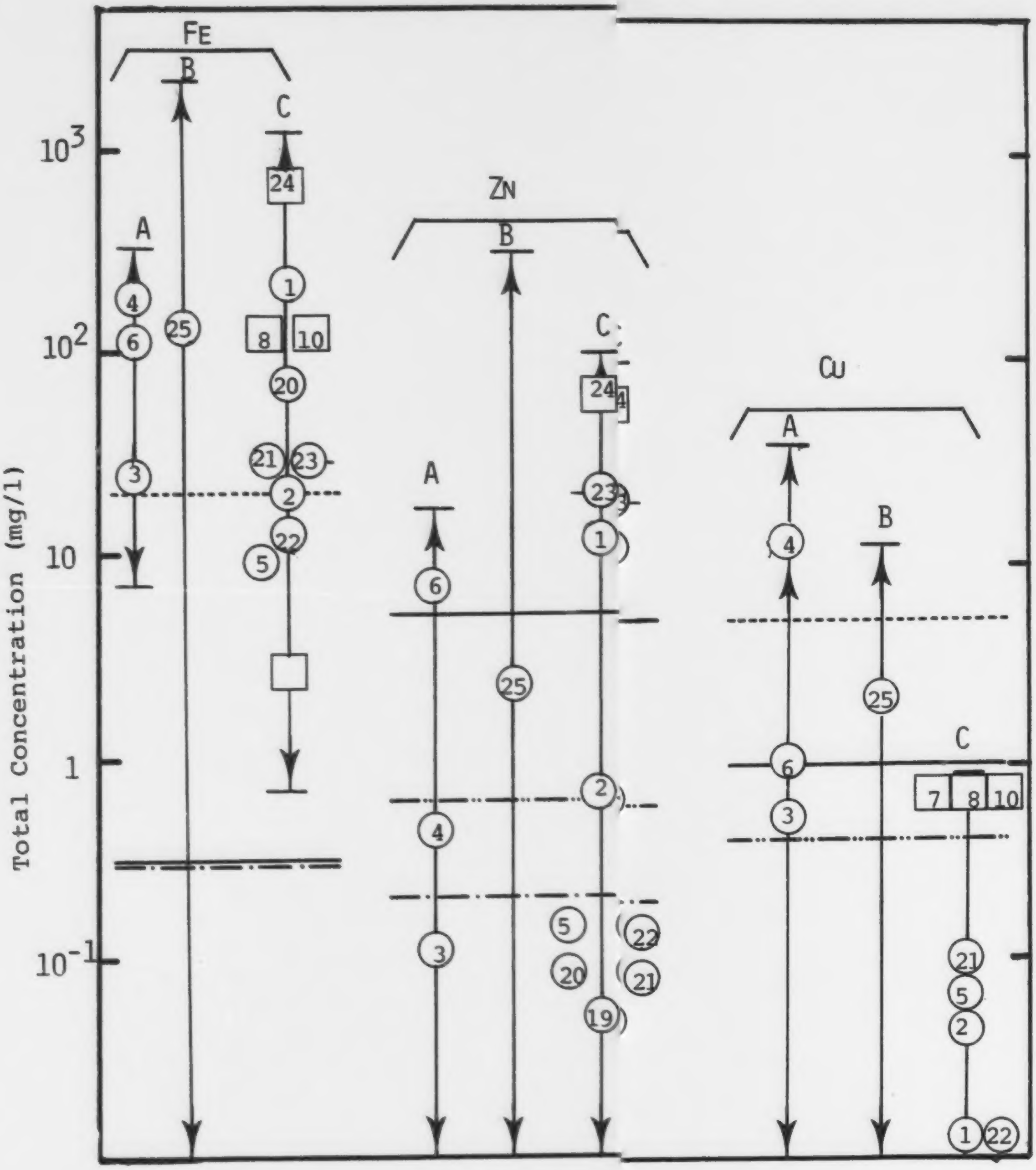

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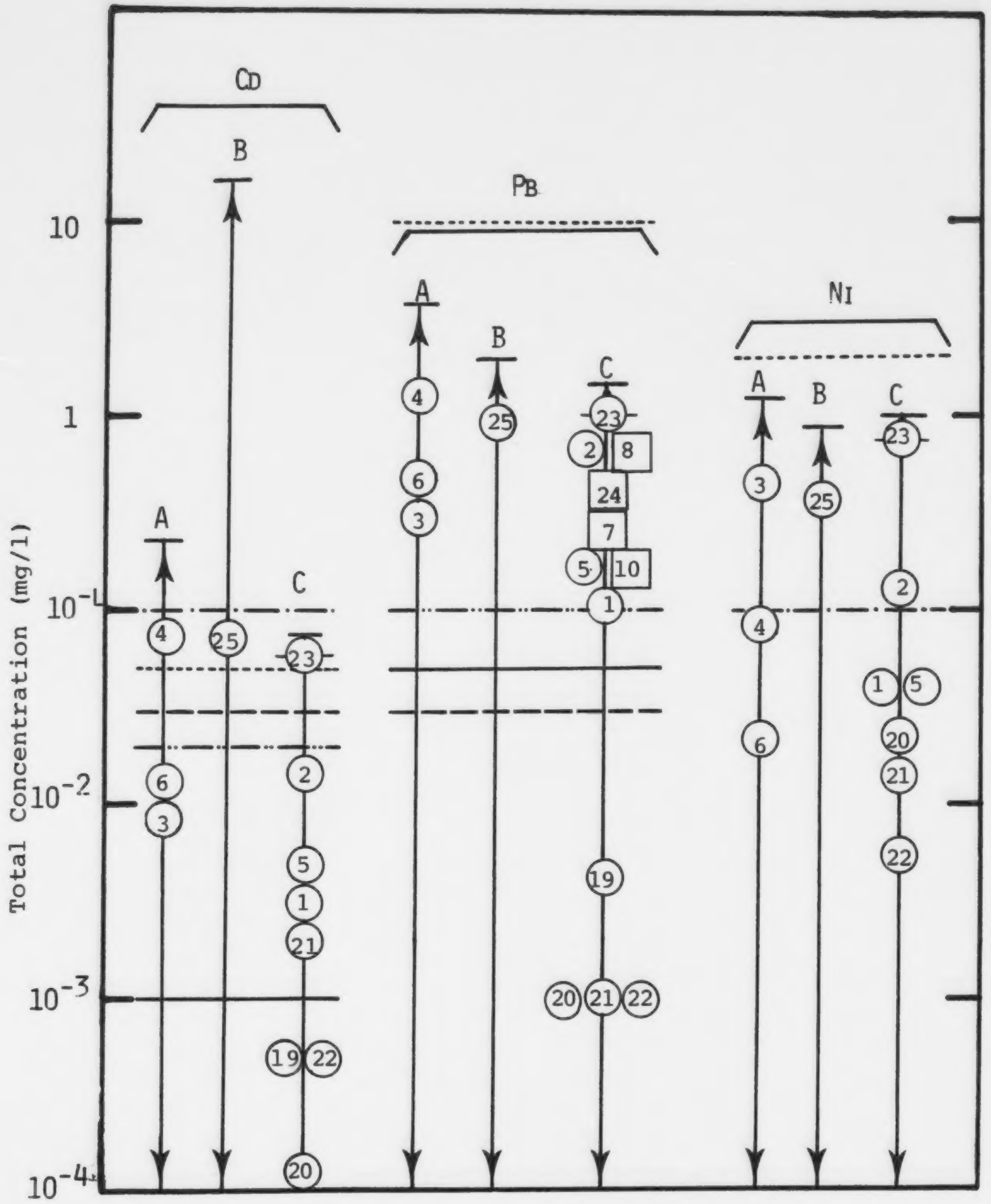

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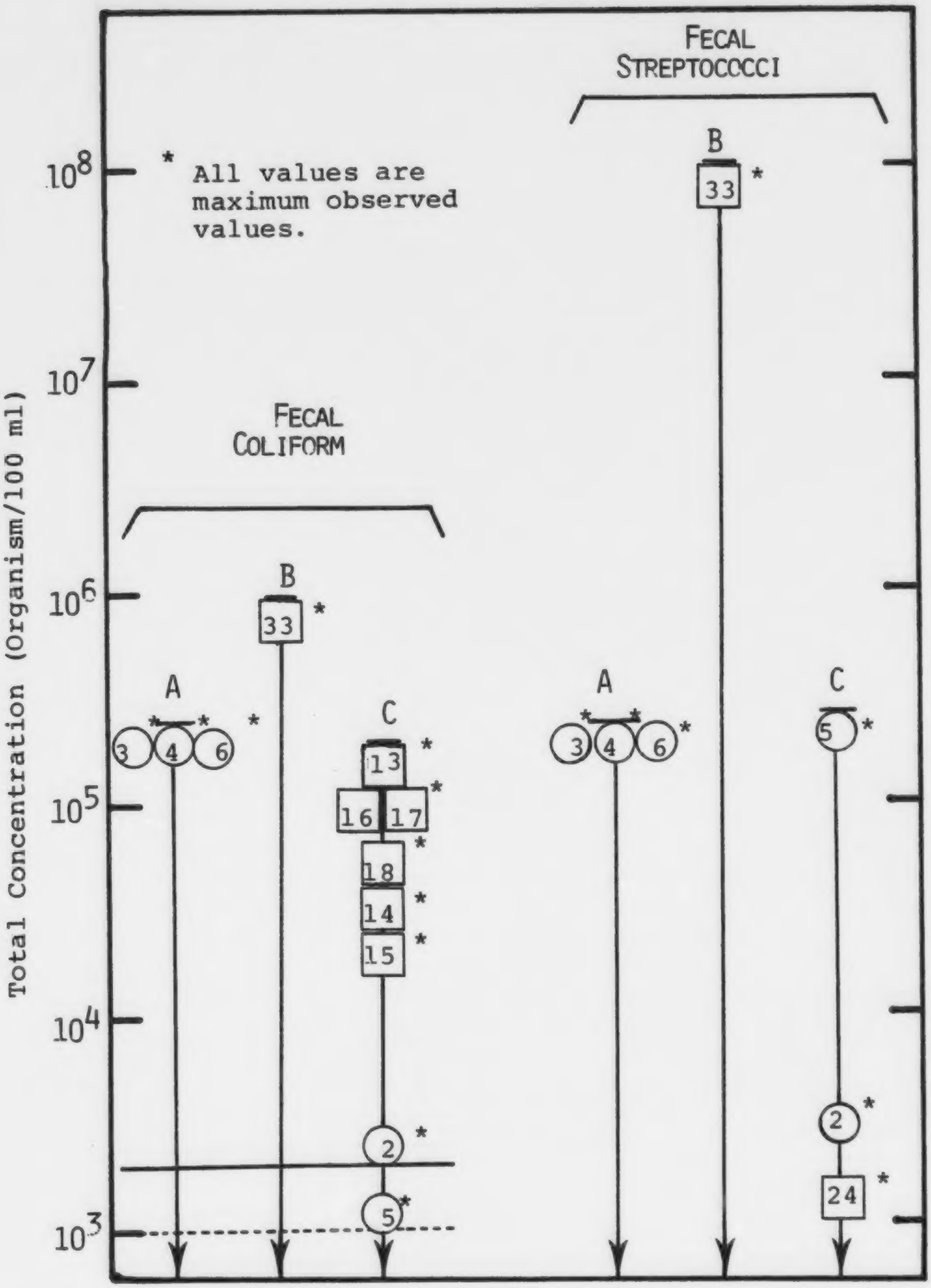

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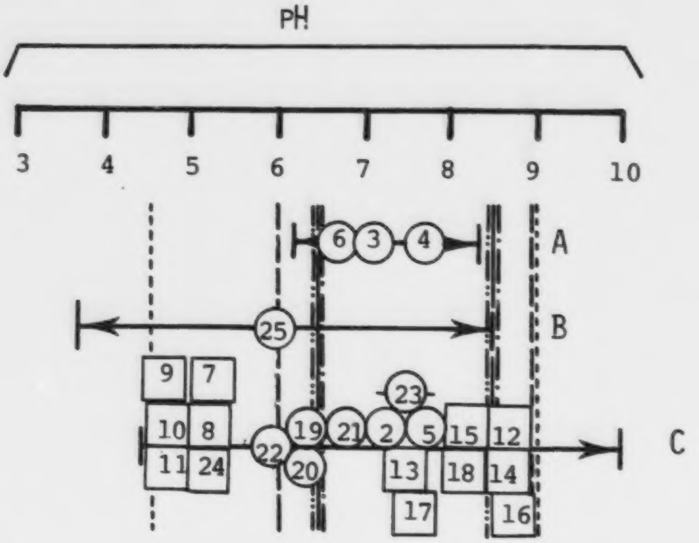

Legend:

A - Sludge-only landfills
B - Refuse-only landfills
C - Sludge/refuse codisposal landfills

○ Landfill

□ Field Test Cell

-○- Laboratory Column Study

WATER QUALITY CRITERIA

——— EPA PUBLIC WATER SUPPLY

------- EPA AGRICULTURAL (IRRIGATION WATER)

— — — EPA FRESH WATER (AQUATIC LIFE)

—·— EPA MARINE WATER (AQUATIC LIFE)

—··— STATE OF NEW YORK, MISSOURI GROUND WATER

(Boxed and circled references are presented in Appendix B. Position of boxes and circles represent the arithmetic means reported by cited references)

Figure 12 (Concluded)

- Marine water (aquatic life).

Within the category, the water quality criteria are from several entities: the Environmental Protection Agency (EPA), National Academy of Science (NAS), National Technical Advisory Committee (NTAC), and various state agencies (95,96,97,98). Various EPA and state criteria have been superimposed on the respective leachate constituents in Figure 12 to facilitate the assessment of potential water quality impacts of leachates from sludge landfilling activities.

Public water supply criteria have been included in this discussion since ground-water aquifers are a source of drinking water for many municipalities. Criteria for fresh water and saline water as receiving water bodies have been included since leachates from landfills may find access into surface waters. Theoretically, ground water that has been contaminated by sludge leachates can also be discharged into surface waters. Agricultural water criteria have been included for comparison because major ground-water aquifers may be used to supply water for irrigation purposes.

The Federal Water Pollution Control Act of 1972 (Public Law 92-500) established the framework for water-quality control laws and regulations. Under this law, the states retain the primary responsibility for water-quality protection. Therefore, numerical criteria available from selected states are also used for comparison.

Public water supply criteria--EPA is authorized by the Safe Drinking Water Act of 1974 to establish drinking water standards. The important parameters developed under this law are listed in Table 28. The numerical values are compiled from the EPA National Interim Primary Drinking Water Regulations (40 CFR 141; 40 FR 59565, December 24, 1975; Amended by 41 FR 28402, July 9, 1976) and EPA National Secondary Drinking Water Regulations (40 CRF 143, March 31, 1977). The National Academy of Science (NAS) and National Technical Advisory Committee (NTAS) proposed public water supply criteria are also listed in the same table for purposes of comparison.

Freshwater (aquatic life) criteria--The water quality criteria for freshwater aquatic life is also delineated in Table 28. There are several freshwater criteria for aquatic life, wildlife, or recreational waters. Only the water quality criteria for aquatic life are listed in Table 28, since for the above-mentioned uses, the criteria for aquatic life are the most strict.

Irrigation water criteria--Since sludge leachates may contaminate surface or ground waters used for irrigational purposes, irrigation water criteria are also listed in Table 28

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TABLE 28. EPA[*] AND PROPOSED NAS[§] NTAC[†] NUMERICAL CRITERIA FOR WATER QUALITY

Parameter	Public Water Supply Criteria			Freshwater (Aquatic Life) Criteria		
	EPA	NAS	NTAC	EPA	NAS	NTAC
pH	6.5 - 8.5[a]	5 - 9	6 - 8.5	6 - 9	6 - 9	6 - 9
BOD (mg/l)	(not considered)	--	--	--	--	--
COD (mg/l)	--	--	--	--	--	--
TOC (mg/l)	--	--	--	--	--	--
Total Dissolved Solids (mg/l)	500[b]	NL (no limit)	500	Bioassays	--	50 Milimoles
NH_3 - N (mg/l)	0.5[c]	0.5	0.5	0.02	0.02	Flow through bioassay
NO_3 - N (mg/l)	10[a]	10	10	--	Maintain existing NO_3- P ratio	--
Ortho - P (mg/l)	0.1[c]	0.1	0.1	--	--	--
Cl (mg/l)	250[b]	--	--	--	--	--
Cd (mg/l)	0.01[a]	0.1	0.1	0.03[e] 0.004[f]	0.03[e] 0.004[f]	$\frac{1}{30}$ TL_m[g]
Cu (mg/l)	1.0[b]	1.0	1.0	$\frac{1}{10}$ LC_{50}[h]	$\frac{1}{10}$ LC_{50}	$\frac{1}{10}$ TL_m
Fe (mg/l)	0.3[b]	0.3	0.3	--	--	--
Mn (mg/l)	0.05[b]	0.05	0.05	--	--	--
Pb (mg/l)	0.05[a]	0.05	0.05	0.03	0.03	--
Hg (mg/l)	0.002[a]	0.002	--	0.2	0.2	--
Zn (mg/l)	5.0[b]	5.0	5.0	$\frac{5}{1000}$ LC_{50}	$\frac{5}{1000}$ LC_{50}	$\frac{1}{100}$ LC_{50}
Ni (mg/l)	NL	NL	--	$\frac{1}{50}$ LC_{50}	$\frac{1}{50}$ LC_{50}	--
Fecal Coliforms[d]	2,000	2,000	2,000	--	--	--
Fecal Streptococci[d]	--	--	--	--	--	--

(Continued)

[*] U. S. Environmental Protection Agency

[+] National Academy of Science

[§] National Technical Advisory Committee

[a] EPA Interim Primary Drinking Water Standard

[b] EPA National Secondary Drinking Water Regulations

[c] Proposed water quality criteria for public supply

[d] Organisms/100 ml.

[e] Hard water-all organisms

[f] Soft water-all organisms

[g] Median tolerance limit-The concentration of a test material in a suitable diluent(experimental water) at which just 50% of the test animals are able to survive for a specified period of exposure.

[h] Median lethal concentration-The concentration of a test material that causes death to 50% of a population within a given time period.

[i] For use continuously on all soils

[j] For use up to 20 years on fine textured soils a pH between 6.0 and 8.5

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TABLE 28. (Continued)

Parameter	Agricultural Water (Irrigation) Criteria			Marine Water (Aquatic Life) Criteria				
							State of California	
	EPA	NAS	NTAC	EPA	NAS	NTAC	50% of Time	10% of Time
pH	4.5 - 9	4.5 - 9	4.5 - 9	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	<0.2 units change	<0.2 units change
BOD (mg/l)	--	--	--	--	--	--	--	--
COD (mg/l)	--	--	--	--	--	--	--	--
TOC (mg/l)	--	--	--	--	--	--	--	--
Total Dissolved Solids (mg/l)	2000-5000 tolerant; 500-1000 sensitive	2000-5000 tolerant; 500-1000 sensitive	500 tolerant; 5000 sensitive	--	--	--	--	--
NH_3-N (mg/l)	--	--	--	0.4	0.4	$\frac{1}{20}$ LC_{50}	40	60
NO_3-N (mg/l)	NL	NL	--	--	--	--	--	--
Ortho-P (mg/l)	--	--	--	0.01	0.01	--	--	--
Cl (mg/l)	--	--	--	--	--	--	--	--
Cd (mg/l)	0.01[i] 0.05(20 yr)[j]	0.01 0.05(20 yr)	.005 0.05(20 yr)	0.1	0.01	--	0.02	0.03
Cu (mg/l)	0.2 5.0(20 yr)	0.2 5.0(20 yr)	0.2 5.0(20 yr)	$\frac{1}{100}$ LC_{50}	$\frac{1}{100}$ LC_{50}	--	0.2	0.3
Fe (mg/l)	5 20(20 yr)	5 20(20 yr)	--	0.3	0.3	--		
Mn (mg/l)	0.2 10(20 yr)	0.2 10(20 yr)	2 20(20 yr)	0.1	0.1	--		
Pb (mg/l)	5 10(20 yr)	5 10(20 yr)	5 10(20 yr)	$\frac{1}{50}$ LC_{50}	$\frac{1}{50}$ LC_{50}	--	0.1	0.2
Hg (mg/l)	--	--	--	0.1	0.1	--	.001	.002
Zn (mg/l)	--	2.0 10(20 yr)	5 10(20 yr)	0.1 0.2	--	--	0.3	0.5
Ni (mg/l)	0.2 2.0(20 yr)	0.2 2.0(20 yr)	0.5 2.0(20 yr)	0.1	1.0	--		
Fecal Coliforms[d]	1000	NL	NL	--	--	--	--	--
Fecal Streptococci[d]	--	--	--	--	--	--	--	--

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TABLE 28. (Continued)

Parameter	Groundwater Contaminant Limits		
	State of New York		State of Missouri
	Schedule 1	Schedule 2	Maximum Value Allowed
pH	6.5 - 8.5	6.5 - 8.5	--
BOD (mg/l)	--	--	--
COD (mg/l)	--	--	--
TOC (mg/l)	--	--	--
Total Dissolved Solids (mg/l)	--	--	--
NH_3-N (mg/l)	--	--	--
NO_3-N (mg/l)	20	10	10
Ortho-P (mg/l)	--	--	--
Cl (mg/l)	--	--	--
Cd (mg/l)	0.02	0.01	0.03
Cu (mg/l)	0.40	0.2	0.02
Fe (mg/l)	--	--	--
Mn (mg/l)	--	--	--
Pb (mg/l)	0.10	0.05	0.05
Hg (mg/l)	--	--	--
Zn (mg/l)	0.60	0.30	0.10
Ni (mg/l)	--	--	--
Fecal Coliforms[d]	--	--	--
Fecal Streptococci[d]	--	--	--

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for comparison. Irrigation water quality regulations account for the short-term effects on crop quality, long-term effects on soil characteristics and surrounding ground water, and the intended use of the crop. Water classified as irrigation water is generally applied to (1) agricultural crops, (2) pasture land, (3) turf and landscape, and (4) stock watering. Absolute limits on irrigation water are difficult to establish due to a number of site-specific factors, e.g., soil type, climate, irrigation practices, etc. Table 28 presents general limits for irrigation water constituents, as suggested by EPA, NAS, and NTAC for both continuous and short-term (up to 20 years) use.

Marine water-quality criteria (aquatic life)--Four kinds of marine water-quality criteria for aquatic life are also included in Table 28, i.e., criteria from EPA, NAS, NTAC, and the state of California (98). State of California marine water quality criteria have been included for comparative purposes. Since sludge landfill leachates may enter marine water from coastal areas, the marine water quality criteria must also be examined in evaluating the potential impact of the leachates.

Ground-water protection criteria--State regulatory agencies are authorized to protect both surface and subsurface waters. Many states currently have specific criteria for ground-water protection. The specific contaminant limits established by the states of New York and Missouri are delineated in Table 28.

Potential Water Quality Impacts: Comparison of Leachate Concentrations to Applicable Criteria--

Comparison of leachate data from each of the three landfill types presented in Figure 12 (i.e., sludge-only, refuse-only, and sludge/refuse codisposal) reveals some interesting trends which are described below. Potential water quality impacts from sludge landfilling are also presented by comparing leachate concentration ranges with previously described water quality criteria. Note that the various criteria are compared to levels of contaminants in the leachates prior to any dilution by receiving waters or soil attenuation, and thus represents a "worst case" condition.

COD--Figure 12 shows that the maximum COD concentration observed for sludge-only landfill leachates (23,283 mg/l) are substantially below the maximum values observed for refuse-only and codisposal leachates (89,520 and 86,420 mg/l, respectively). Based on these values, one might assume that refuse, common to refuse-only and codisposal landfills, is the source of higher COD levels in leachates. However, considering the high volatile organic content of the raw primary and biological sludges (Table 1) used in the sludge-only landfills being considered (Appendix A), the results are somewhat paradoxical.

Based on several studies, it is speculated that the elapsed time following sludge placement is a key factor influencing constituent concentrations in sludge leachates. For example, Sikora *et al*. (83) found that chloride levels in shallow wells within a sludge trench site peaked some 18 months after entrenchment of undigested lime stabilized sludge (20% solids). Stone (39) observed BOD$_5$ levels to peak roughly one year following placement of raw primary sludge into field test cells. Thus, the concentration of sludge landfill leachate constituents is a time related phenomenon; therefore, comparing maximum levels of leachate constituents regardless of time or other normalizing factors can be misleading. This is particularly true when there is a large discrepancy in the number of data points represented in compared entities, such as sludge-only and co-disposal landfill leachates (for which there are few data) and refuse-only leachates (for which there are many data). Thus, the surprisingly low COD values observed for sludge-only leachates are probably a result of insufficient data, which are not representative of the time factor, rather than a characteristic of sludge leachates.

Regarding water quality impacts, there are presently no COD criteria available (Table 28) for comparative purposes. Background levels of COD in natural waters will be compared. Whipple *et al*., (99) analyzed natural waters for BOD$_5$ and COD at different points along a stream originating in an upland drainage basin, and progressing through a variety of habitats. The results are listed in Table 29.

TABLE 29. COD AND BOD$_5$ LEVELS IN A NATURAL WATER (99)

Source	COD (mg/l)	BOD$_5$ (mg/l)
Upland stream	6.3	-- (negligible)
Stream below farmlands	9.0	--
Stream below swamp	49.5	--
Lower end of reservoir, surface sample	33.0	--
Lower end of reservoir, bottom sample	34.0	--
Upland stream above city	5.4	--
Stream below sewer outfall	24.0	--

Comparing the above COD levels to the very high COD levels in sludge and refuse leachates, it is indicated that the discharge of such leachate to receiving waters could result in a severe degradation of water quality.

BOD$_5$--BOD$_5$ levels were not reported for sludge-only landfill leachates in the studies reviewed. Comparing maximum BOD_5 concentrations in refuse-only and codisposal leachates reveals little difference (33,362 and 38,250 mg/l respectively).

The high concentrations of BOD_5 indicated could present a significant threat to the quality of receiving waters. Whipple *et al.*, (99) found BOD_5 levels in a natural water (Table 29) to be negligible at all points along an upland drainage basin. High BOD_5 leachate contributions to such waters may lead to eutrophic conditions.

TOC--Figure 12 shows the maximum level of TOC for refuse-only landfill leachates (28,000 mg/l) nearly doubles that of sludge-only and codisposal landfill leachates (approximately 14,000 mg/l). Reasons for the difference are not apparent, although far less data comprise the range of values indicated for sludge-only and codisposal leachates in comparison to refuse-only leacnates.

To date, there are no criteria for TOC levels in receiving waters. However, due to the strong complexing capability between organic matter and trace metal contaminants, the levels of organics in leachates (TOC) may become most important in predicting the potential increase of mobile inorganic material to potentially toxic levels. In freshwater bodies, concentrations of a few parts per million are encountered although concentrations may be as high as 50 ppm (100) (e.g., in bog or swamp waters). Concentrations of TOC range from 0.1 to 10 ppm in the ocean with an average value of about 1 ppm in the surface water and lower values in deep water (100-108). The TOC levels in sludge and refuse landfill leachates are substantially higher than the background TOC levels indicated.

TS--In comparing the total solids (TS) ranges reported for the various leachates, a trend of higher maximum concentrations for refuse-only leachates is observed (Figure 12). The maximum TS level reported for refuse-only leachates (59,200 mg/l) are more than double the maxiumum level reported for sludge-only and codisposal leachates. Water quality criteria for total solids are unreported in the literature.

TDS and Specific Conductivity--Total dissolved solids values were unreported for sludge-only landfill leachates in the reviewed literature. Maximum reported TDS values for refuse-only leachates (44,,900 mg/l) were slightly greater then those of codisposal leachates (33,000 mg/l). Judging from total solids (TS) data, TDS concentrations for sludge-only leachates should be of a similar magnitude as codisposal leachates. Though specific conductance values indicate that dissolved solids of sludge-only leachates are substantially less than codisposal leachates, the data may be misleading because of limited data available.

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The EPA secondary drinking water regulations limit TDS levels to a maximum of 500 mg/l. At leachate TDS levels indicated in Figure 12, the EPA drinking water criteria are exceeded by a significant amount. The maximum EPA Agricultural (irrigation) water standards at 5000 mg/l would also be exceeded by these high TDS levels. No standards have been established for either marine water (aquatic life) or ground-water criteria.

Phosphorus--Figure 12 shows that no total phosphorus values were reported for sludge-only leachates, and that the maximum total phosphorus level of refuse-only leachates (398 mg/l) is more than twice the level reported for codisposal leachates (135 mg/l). Phosphorus levels in sludge generally range from 1 to 3%, of which orthophosphorus is thought to be a major component (47). Judging from the high levels of phosphorus in sludge, sludge additions to refuse are not expected to reduce phosphorus levels in leachates as reflected by the data presented.

EPA, NAS, and NTAC drinking water criteria for orthophosphate are all 0.1 mg/l. EPA and NAS marine water (aquatic life) criteria are more stringent at 0.01 mg/l. Observed phosphorus levels in refuse-only and codisposal leachates greatly exceed these criteria. Orthophosphate additions to natural waters may lead to algal blooms, oxygen depletion, and eutrophic conditions if acting as a limiting nutrient.

Ammonia-nitrogen--Maximum NH_4-N concentrations reported in sludge-only, refuse-only, and codisposal leachates were 3407, 1105, and 1760 mg/l, respectively. High levels of NH_4-N in sludge leachates are indicative of organic nitrogen mineralization and the absence of dissolved oxygen, preventing oxidation of NH_4 to NO_3. This phenomenon is discussed in more detail below.

Mean concentrations of nitrogen in sewage sludges range from 1 to 5% of dry sludge solids (Table 10). Most of the nitrogen remaining in dewatered sludge is organically bound, and mineralization, the conversion of organic nitrogen to NH_4-N, proceeds slowly. For instance, during land treatment of sludge, available data indicate that from 15 to 35% of the organic nitrogen is mineralized the first year of application (109-112). At soil pHs in the range 4.5 to 8.5, and when the dissolved oxygen exceeds 0.2 mg/l, the NH_4-N formed by mineralization of organic N is rapidly converted to NO_3-N. Anaerobic conditions inhibit the oxidation of NH_4-N to NO_3-N; therefore, high levels of NH_4-N can be present.

The maximum levels of NH_4-N in all leachates are well above existing water quality criteria (Table 28) for drinking water, fresh water (aquatic life), and marine water (aquatic life).

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The State of California has effluent quality requirements for soluble ammonia in ocean discharges, i.e., ammonia-nitrogen should be kept less than 40 mg/l for 50% of the time and 60 mg/l for 10% of the time. These criteria are based on a dilution factor of 200. Ground waters and irrigation waters have no criteria. Thus, it appears the ammonia levels may become a limiting factor for sludge and refuse leachates intercepting ground waters which discharge to surface and ocean waters if sufficient dilution is not attained.

Nitrate-nitrogen--maximum nitrate level reported for sludge-only leachates (400 mg/l) is well-above the maximum NO_3-N level reported in refuse-only (10.3 mg/l) and codisposal 25.9 mg/l) leachates, as shown in Figure 12. Sikora et al. (83) detected NO_3-N in the 30 mg/l range in surface and drainage waters from a sludge-only (undigested, lime stabilized) entrenchment site. Lund et al. (113) reported concentrations of NO_3-N greater than 400 mg/l at a depth of 23 meters below a 20 year old sludge lagoon. On an offsite control at a comparable depth, the concentrations of NO_3-N was 30 mg/l. Because of its human health impairing potential (discussed in Section 6), sludge nitrate could be a limiting factor in sludge landfilling.

Nitrate levels in sludge leachates will depend on several factors, including sludge composition and properties, disposal methods, and soil characteristics (for unlined sites). Fresh, anaerobically digested sludge, for example, will contain very little nitrate, but high levels (1%) of ammonia nitrogen. Given environmental conditions favorable to nitrification, sludge nitrate levels will increase. Considering the high levels of total nitrogen in most WWTP sludges, nitrate should be of primary concern with respect to polluting water resources. EPA, NAS, and NTAC public water supply criteria for nitrate (10 mg/l as N) may be exceeded by nitrate in sludge leachates.

Chloride--Reported upper levels of chloride are 1160, 2467, and 5944 mg/l for sludge-only, refuse-only, and codisposal leachates, respectively. The relatively high levels of chloride (i.e., > 4500 mg/l) in codisposal leachates were reported in field test cell investigations by Emcon Assoicates (90) and Stone (39). Relatively low levels of chloride in sludge-only leachates represents data from active landfill sites.

With the exception of the EPA National Secondary Drinking Water Regulations, there are no regulatory criteria for chloride levels. The EPA standard of 250 mg/l is substantially lower than levels in leachates generated by either sludge landfills or municipal refuse landfills, both of which may exceed 1000 mg/l.

Calcium--Maximum calcium levels reported in refuse-only

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leachates (7200 mg/l) exceed maximum levels reported in sludge-only (2248 mg/l) and codisposal (1420 mg/l) leachates. Ca levels in sludge generally range from 3.3% to approximately 6% (dry sludge solids). These relatively high levels of Ca in sludge are expected to contribute to greater Ca levels in sludge leachates than reported above. Again, relatively limited sludge leachate data is believed responsible for the discrepancy. Though no water quality criteria are reported calcium, Ca is a prinicpal hardness-causing cation.

Magnesium--Figure 12 shows maximum magnesium concentrations in refuse-only leachates (15,600 mg/l) substantially greater than the maximum level in codisposal leachates (1070 mg/l). The cause of such a vast difference is likely related to the paucity of codisposal leachate data. No magnesium levels were reported for sludge-only leachates in the literature reviewed. Like calcium, magnesium is a principal hardness-causing cation, but no water quality criteria is reported in Table 28.

Iron--Figure 12 shows that maximum total Fe concentrations reported in refuse-only leachates (2820 mg/l) greatly exceed levels in sludge-only and codisposal leachates (350 and 1083 mg/l, respectively). Mean concentrations of Fe in sludge generally range from 1 to 2% of dry sludge solids (47). The availability and mobility of Fe in sludge is largely dependent on the Eh of the sludge, i.e., anaerobic conditions favor the solubilization of Fe.

The maximum contaminant level for iron in public water supplies proposed by EPA, NAS, and NTAC is 0.3 mg/l, based on possible aesthetic effects. For marine water (aquatic life) and ground-water quality control, the tolerable level for iron is usually 0.3 mg/l. However, the limit for iron in waters utilized for irrigation purposes can be as high as 20 mg/l for land irrigated up to 20 years. Iron levels in sludge landfill and refuse landfill leachates are extremely high relative to these criteria and present a threat to the aesthetic quality of many natural waters.

Zinc--Like iron, maximum Zn concentrations reported for refuse-only landfill leachates (370 mg/l) are considerably greater than upper values reported for sludge-only and codisposal leachates (17 and 91 mg/l, respectively). The observed difference is believed to be attributable, at least in part, to fewer data for sludge landfilling practices. The potential for sludge-borne organometallic chelates to increase the solubility of Zn in sludge leachates above concentrations in refuse-only leachates is not observed in the available data.

The highest allowable concentration of Zn in public drinking water supplies is 5 mg/l. The reported concentrations of Zn in sludge landfill and refuse landfill leachates exceed

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the drinking water standards. The proposed NAS and NTAC limits for zinc in irrigation water is 2 and 5 mg/l, respectively, and in circumstances when agricultural land is to be used for up to 20 years, the limit is 10 mg/l. EPA marine water criteria (for aquatic life) and states of Missouri and New York ground-water contaminant limits may also be exceeded by reported Zn levels in sludge landfill leachates.

Copper--Figure 12 shows maximum concentrations of Cu in sludge-only leachates (36 mg/l) to exceed Cu values in refuse-only and codisposal leachates (9.9 and 0.81 mg/l, respectively). Copper is another trace metal capable of forming stable complexes with organic ligands (114).

With the exception of codisposal leachates, Figure 12 shows leachate concentrations exceed EPA drinking water, irrigation water, and state of New York ground-water criteria. Because sludge-only and refuse-only leachates indicate such high Cu levels, sludge/refuse codisposal leachates must also be considered a threat to most receiving waters.

Cadmium--Maximum Cd levels reported for refuse-only leachates (17 mg/l) were orders of magnitude greater than maximum Cd levels reported for sludge-only and codisposal leachates (0.22 and 0.072 mg/l, respectively). Additional sludge leachate data is needed before definitive conclusions can be drawn regarding differences in Cd concentrations in sludge landfill and refuse landfill leachates.

The cadmium limit in public drinking water supply set by EPA, NAS, NTAC, is 0.01 mg/l; the limit in waters for other beneficial uses range from 0.004 to 0.05 mg/l. Maximum Cd levels reported in all leachates exceed these water quality criteria. However, the majority of Cd concentration values for sludge landfill (including sludge-only and codisposal) leachates were below 0.05 mg/l (see Appendix A). Where the dilution factor is greater than 2, the potential pollution problems for agricultural (irrigation) water and ground water caused by cadmium can be minimized.

Lead--Maximum lead concentrations are of similar magnitude for leachates of each landfill type (Figure 12), ranging between 1.4 and 3.5 mg/l. Recommended criteria for lead in public water supply and ground water are 0.02 to 0.1 mg/l, respectively. For fresh water (for aquatic life) the lead criteria are more restrictive, with a value of 0.03 mg/l. For marine water discharge in the state of California, the limit is 0.1 mg/l for 50% of the time and 0.2 mg/l for 10% of the time. Agricultural water criteria limit the lead concentration to 5 mg/l for land used greater than 20 years. With the exception of agricultural water criteria, all water quality criteria are surpassed by the upper range of lead reported for each landfill leachate.

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Nickel--Like lead, maximum concentrations of Ni are nearly identical for all leachates, ranging from 0.81 to 1.10 mg/l. Contaminant levels for nickel are proposed for fresh water (aquatic life), marine water (aquatic life), and irrigation waters (see Table 28). Maximum levels of nickel in all leachates are within agriculural water limits for land use up to 20 years, but exceed EPA marine water (aquatic life) standards. Bioassays are proposed for fresh water (aquatic life criteria).

Fecal coliform and fecal streptococci--Figure 12 shows maximum levels of fecal coliform and fecal streptococci to be highest in refuse-only leachates (10^6 and 10^8 organisms/100 ml, respectively) and lowest in sludge-only leachates ($\geq$ 24,000 organisms/100 ml). However, whereas refuse-only leachates have in many cases shown no evidence of fecal contamination (lower limit of 0 organisms/100 ml), sludge-only leachates showed the presence of fecal contamination in all samples. Codisposal leachates also showed the potential for high levels of fecal coliform and fecal streptococci ($> 10^5$ organisms/100 ml).

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Discharges to public water supplies are limited to 2000 fecal coliform/100 ml, according to EPA, NAS, and NTAC water quality criteria. The EPA has established a limit of 1000 organisms/100 ml for irrigation waters. No other fecal coliform or fecal streptococci criteria have been established. Reported fecal coliform and fecal streptococci levels in landfill leachates are clearly in excess of existing water quality criteria, and represent a potential health hazard.

In spite of reported high numbers of fecal coliform and fecal streptococci in sludge or refuse landfill leachates, the leachates can represent an extremely harsh environment for many organisms. Ware (33) cited studies in which significant bacteria populations were found in leachates, but populations decreased in density with time of operation or time of leaching. The inactivation of leachate pathogens (bacteria and viruses) has been attributed primarily to temperature (115,116,117), pH (115,118), metal ions (118), and aliphatic acids (119).

pH--Reported pH ranges in leachates for each type of landfill are as follows: sludge-only leachates, 6.2-8.3, refuse-only leachates, 3.7-8.5, and codisposal leachates, 4.5-9.9. In comparison with sludge-only landfill leachate, the municipal refuse leachate appears to maintain a less limited pH range. In particular, refuse-only leachates can be more acidic (pH = 3.7) than sludge-only leachates (pH = 6.3). Codisposal landfill leachates have the potential to be slightly more acidic (pH = 4.5) than sludge-only leachates, and substantially more alkaline (pH = 9.9) than sludge-only and refuse-only leachates (pH = 8.3 and 8.5, respectively).

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EPA and NTAC public water supply criteria, EPA, NAS, and NTAC marine water (aquatic life) criteria, and state of New York, ground-water limits are violated by the lower pH ranges of each landfill leachate (see Table 28). Refuse-only leachates can be particularly acidic and lower pH values exceed all water quality criteria in Table 28. Likewise, high pHs reported for codisposal leachates violate the upper pH boundary for all water quality criteria. The uppper pH range for sludge-only and refuse-only leachates do not exceed the indicated criteria.

Summary--A comparison of the maximum concentration of leachate constituents and pH range among sludge-only, refuse-only, and sludge/refuse codisposal leachates showed considerable disparity. Refuse-only leachates exhibit (Figure 12) substantially higher concentrations of TOC, TS, Ca, total Fe, Zn, Cd, fecal coliform, fecal streptococci, and a lower pH than sludge-only and codisposal leachates. In comparing sludge-only and codisposal landfill leachates, codisposal leachates show substantially higher concentrations of COD, TS, dissolved solids (specific conductance), Cl, total Fe, Zn, and a wider pH range than sludge-only leachates. Sludge-only leachates show higher concentrations of NH_4-N, NO_3-N, and Cu than refuse-only and codisposal leachates. It should again be noted that considerable less data on leachate concentrations was available for sludge landfilling practices, particularly sludge-only landfills, than for refuse-only landfills. The limited sludge landfill leachate data may have some bearing on the above-mentioned trends.

Leachates from each type of landfill are of sufficient strength to seriously degrade the quality of receiving waters. Various water quality criteria are exceeded by reportedly high concentrations of COD, BOD_5, TOC, TDS, phosphorous, NH_4-N, NO_3-N, Cl, Fe, Cd, Cu, Pb, Ni, fecal coliform, fecal streptococci, and lower ranges of reported pH values in sludge-only, refuse-only, and codisposal leachates, according to available data.

Because landfills are dynamic systems, causes of the aforementioned leachate trends are difficult to establish. It is not at all clear why refuse-only leachate TOC values exceed those for sludge-only and codisposal leachates, particularly where landfilling involves raw primary sludges. Considering the vast microbial population of sludge, it is also surprising that higher maximum levels of leachate fecal coliform and fecal streptococci are observed in refuse-only leachates in comparison to sludge landfill leachates. With regard to metals, the lower range of pH observed in refuse-only leachate may be responsible for the higher levels of certain metals in these leachates in comparison to sludge-only and codisposal leachates. The pH of sludge-only and codisposal leachates does not extend to the low levels observed for refuse-only leachates, perhaps due to the buffering capacity provided by sludge alkalinity (Table 1).

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The higher concentrations of ammonia and nitrate-nitrogen in sludge-only and codisposal leachates can be attributable to the high nitrogen levels in sludge.

Factors Influencing Leachate Composition--
The composition of leachate is influenced by several factors, some of which were mentioned previously. Factors which affect the leachate composition of refuse landfills has been the topic of considerable research, reviewed by Lu, et al. (120). Certain factors, such as waste composition and landfill moisture, are found to have significant influence on leachate composition (120). By managing these factors effectively, the composition of leachate can be controlled so that potential threats to water quality posed by leachates can be minimized.

This section will examine the effects of manageable factors such as types of sludge, disposal methods, and sludge/refuse mix ratios on the composition of sludge landfill leachates. The concentration of key leachate constituents as a function of age, or time since sludge placement, will also be discussed.

Types of sludge--Landfilled wastewater residuals are a primary factor influencing leachate constituent concentrations, since the residuals are the source of leachate contaminants. By distinguishing between the composition of leachates of individual residuals, the potential environmental impacts related to landfilling of the individual and combined residuals can be better defined.

Figures 13 - 16 compare the pH, specific conductivity, and concentrations of COD and NH_4-N in sludge landfill leachates among individual and combined WWTP residuals. Leachate data used to develop the figures were derived from three sources: active landfill sites, field test cells simulating actual landfill conditions, and laboratory columns. It is important to note that much of the data was derived from codisposal investigations and that leachate compositions may reflect contributions by refuse. In each figure, the range of reported values is given (the arrowed region) along with the arithmetic mean of values reported by each of the numbered references. Where a reference reported only a single value for a constituent or parameter, this value is indicated (since, in this case, there is no mean value). The legend for the references shown in Figures 13-16, is prepresented in Appendix B.

In comparing pH values among the various WWTP sludges (Figure 13), raw primary sludge leachate shows lower reported pH values (approximately 4.5) than the leachates of anaerobically digested or combined sludges. Leachates of anaerobically digested sludge exhibit the highest pH (ranging to approximately 9.9) of the represented sludge types and combinations. The data

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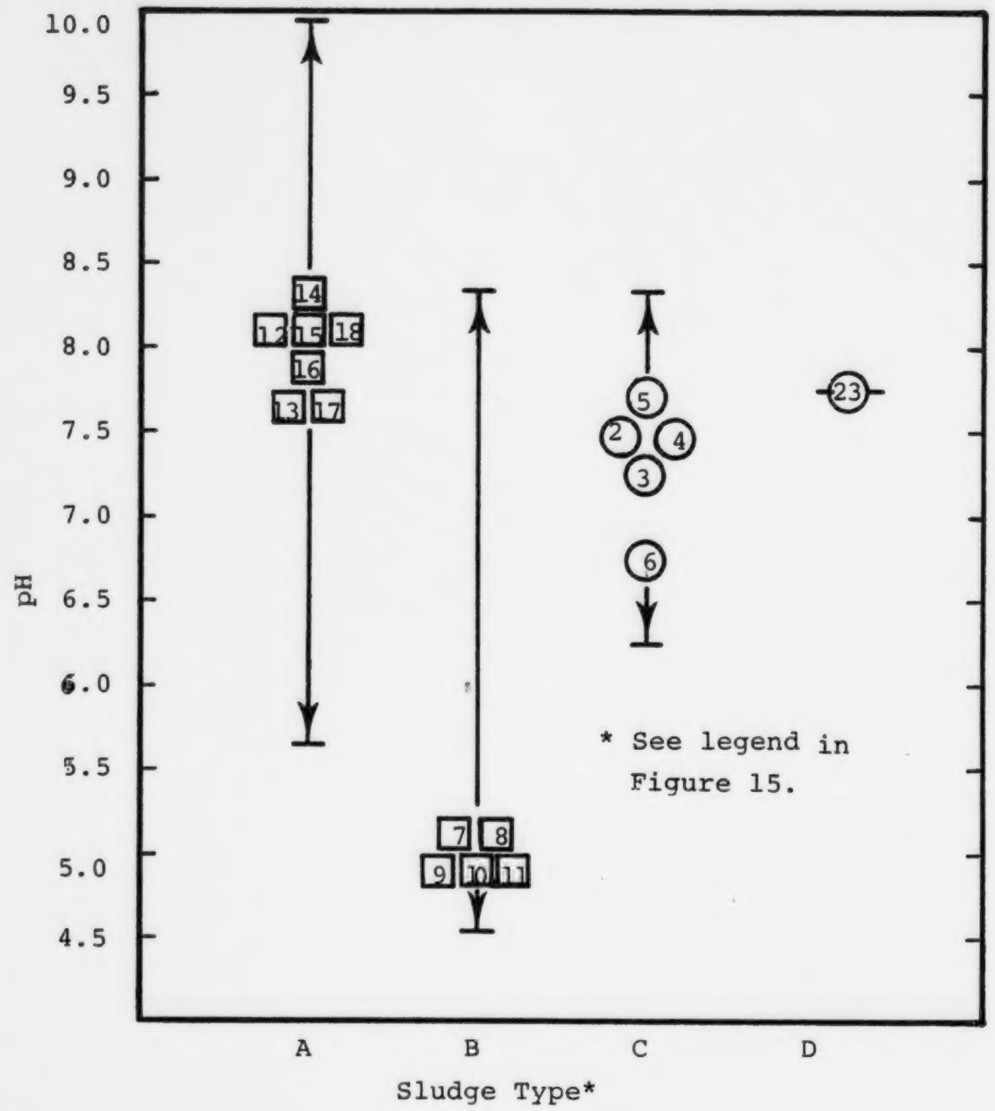

Figure 13. Effect of sludge type on leachate pH.

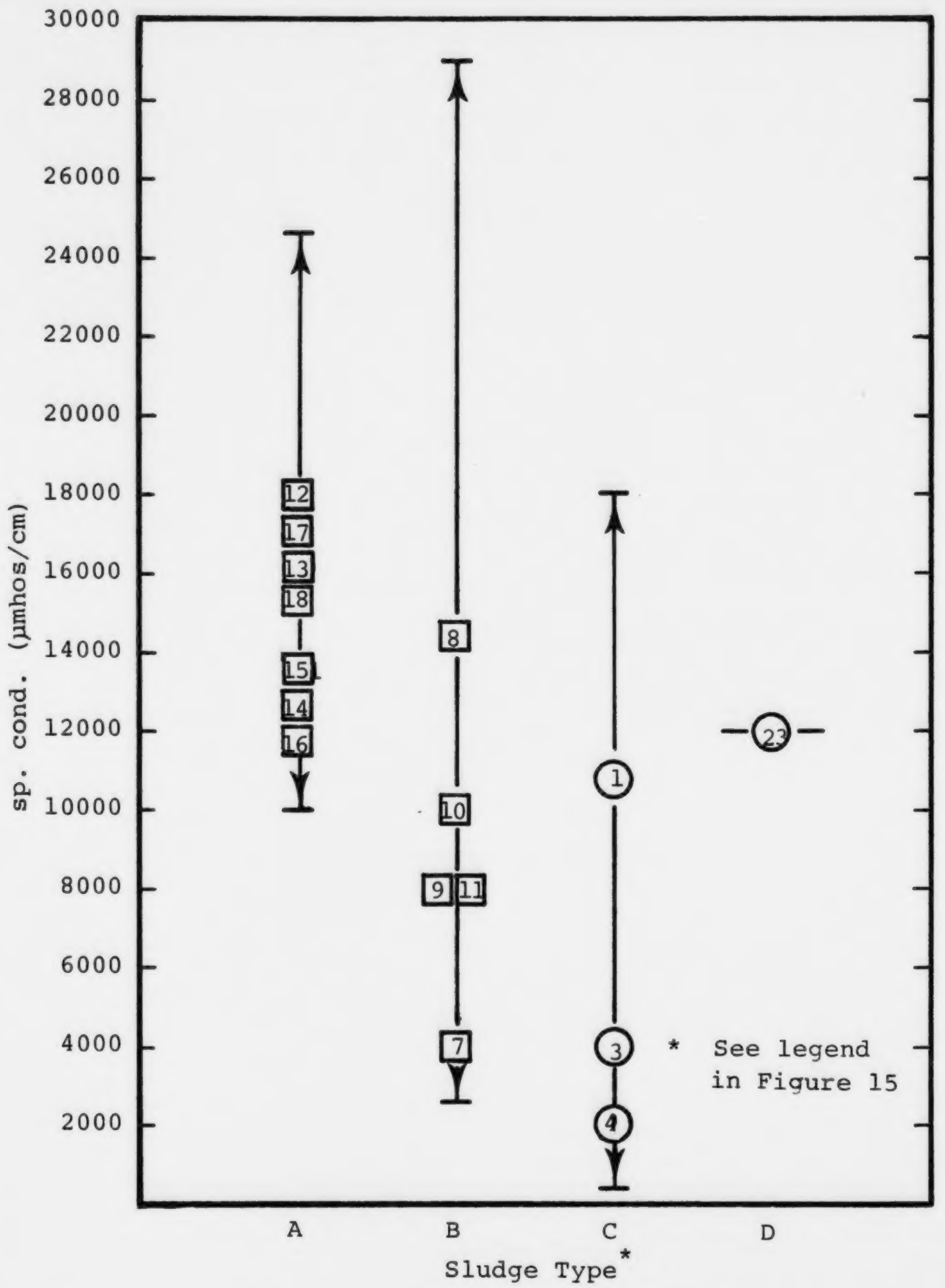

Figure 14. Effects of sludge type on leachate specific conductivity.

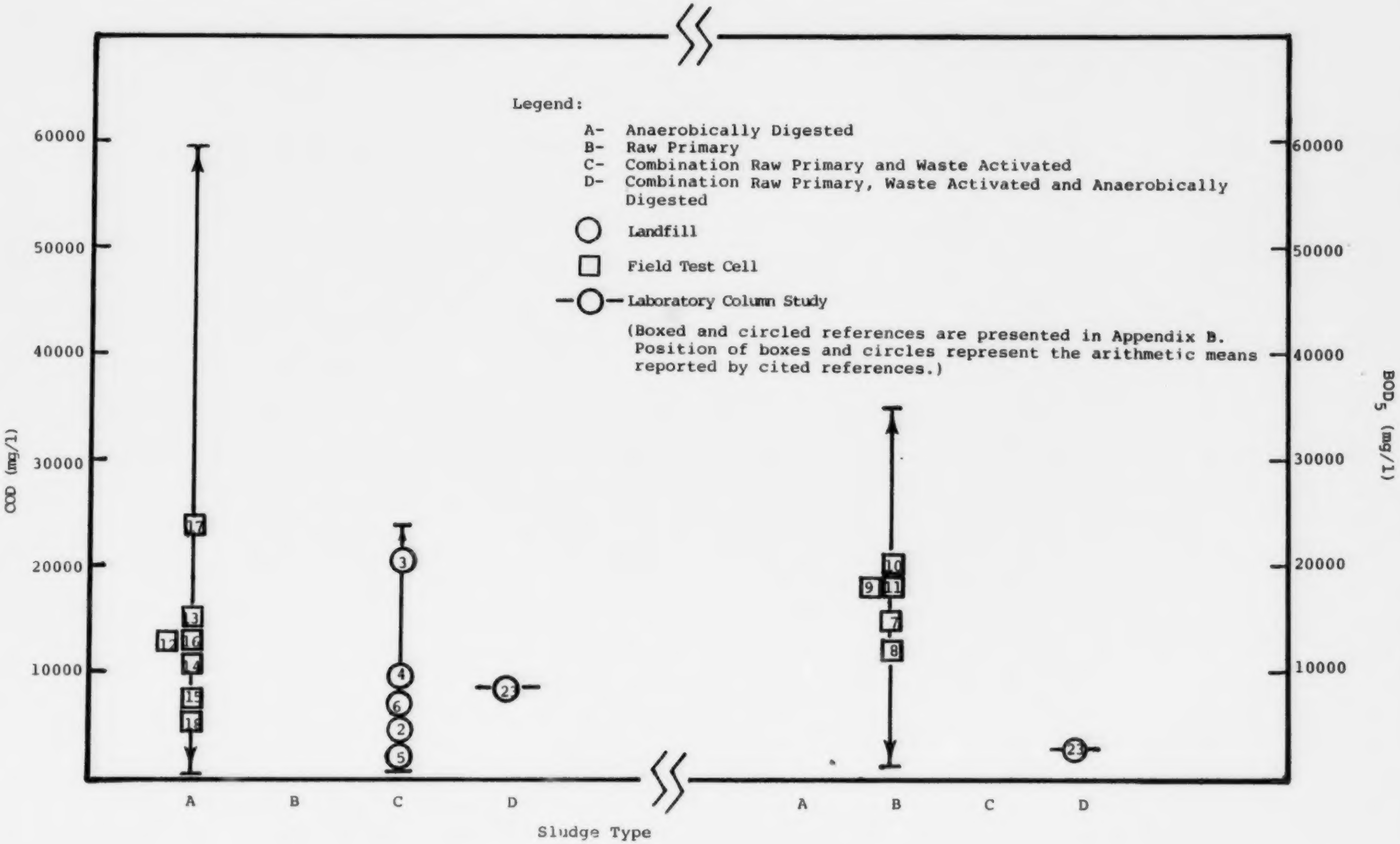

Figure 15. Effect of sludge type on leachate COD.

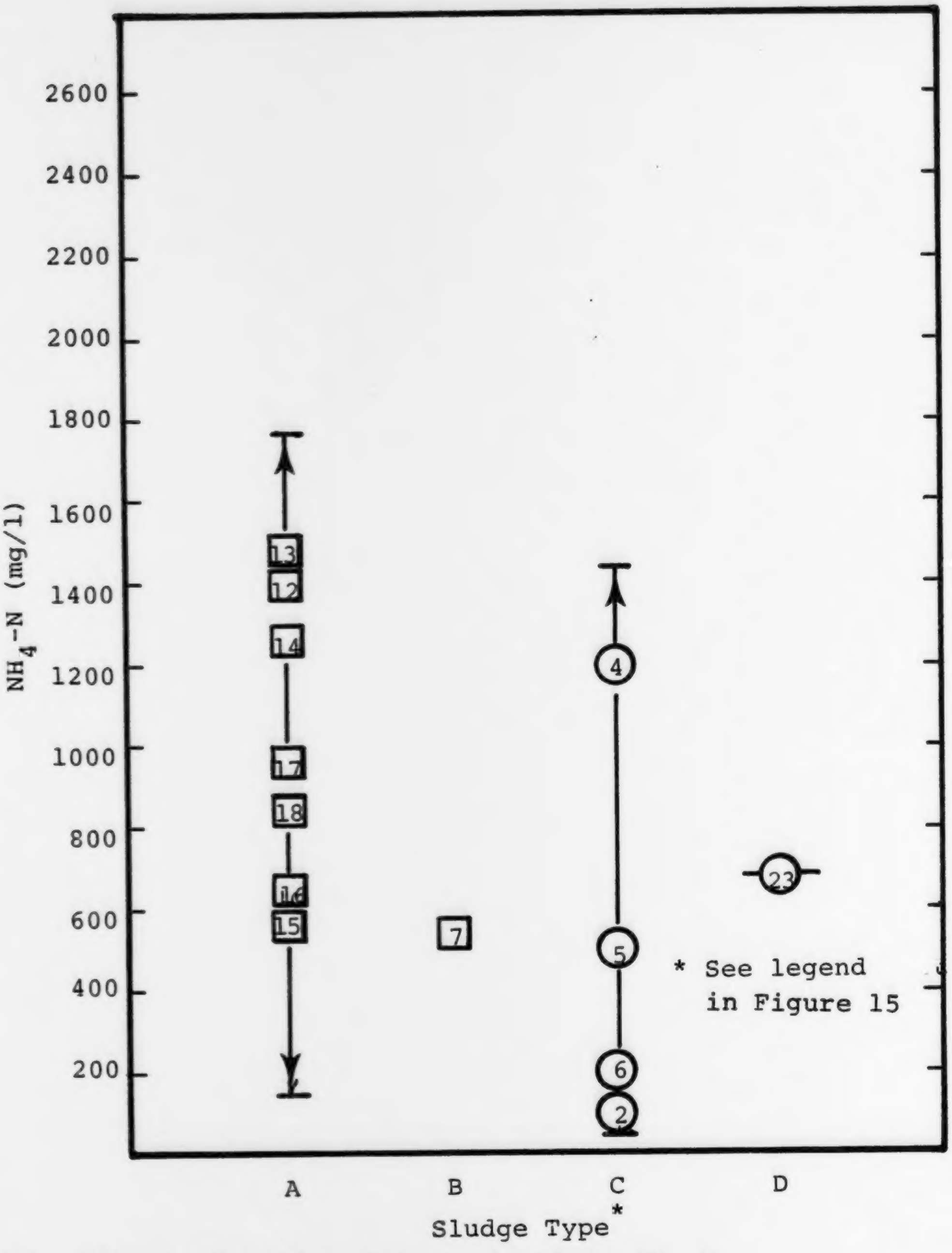

Figure 16. Effect of sludge type on leachate NH_4-N.

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indicate that sludge stabilization by anaerobic digestion may inhibit the production of organic acids by the digested sludge once placed in the landfill. Raw sludges, high in biodegradable organics, will produce organic acids during anaerobic decomposition of the sludge, thus lowering the pH of the sludge and leachates which can be formed.

Figure 14 compares the specific conductivity of leachates from each of the sludges. Raw primary sludge exhibits the highest leachate specific conductivity of the sludges and sludge combinations, with values exceeding 28,000 µmhos/cm. Leachates of anaerobically digested sludge, however, show the highest mean conductivity values, followed by the raw primary sludge leachates and combined sludge leachates.

Leachate COD values for the different sludges are compared in Figure 15. Maximum leachate CODs are exhibited by anaerobically digested sludges (approximately 59,000 mg/l), COD values for raw primary sludge leachates were not reported. Raw primary sludges did, however, show maximum leachate BOD_5 values of approximately 35,000 mg/l. Mean BOD_5 values of primary sludges are of similar magnitude to mean COD values for anaerobically digested and combined sludge leachates. Comparative BOD_5 values for other sludge leachates were also not reported, with the exception of a single combined sludge. Besides showing that anaerobically digested sludge may exhibit relatively high leachate COD values, Figure 15 gives a rather limited comparison of sludge's polluting potential.

Figure 16 shows the concentration of NH_4-N in leachates from the various sludges reported. The highest concentration of NH_4-N is displayed by anaerobically digested sludge (approximately 1800 mg/l), though limited data was available for this comparison. The leachate of raw primary and activated sludge combinations exhibited values in excess of 1400 mg/l.

In summary, raw primary sludge exhibits a leachate of lower pH and higher specific conductivity then the anaerobically digested or combined sludges examined. The data also show that leachates of anaerobically digested sludge can exhibit a high pH and high levels of COD and NH_4-N relative to the remaining sludges. Note, however, that the leachate data may reflect refuse contributions from codisposal landfill operations.

Disposal method--Figures 17-20 compare the pH, specific conductivity, and concentrations of COD and NH_4-N in leachates of seven separate sludge and/or refuse landfilling methods. The landfilling methods fall into one of three categories:

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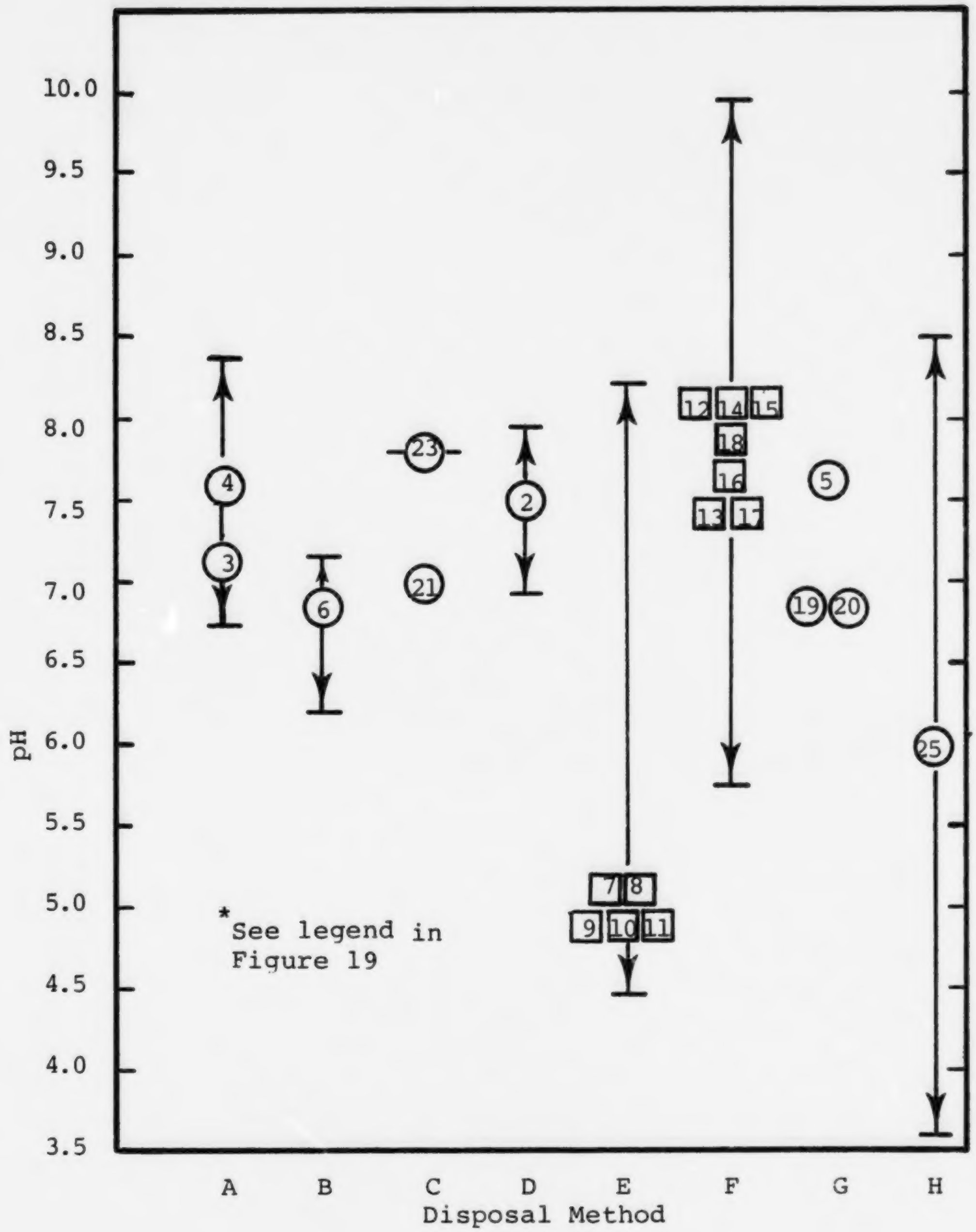

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Figure 17. Effect of disposal method on leachate pH.

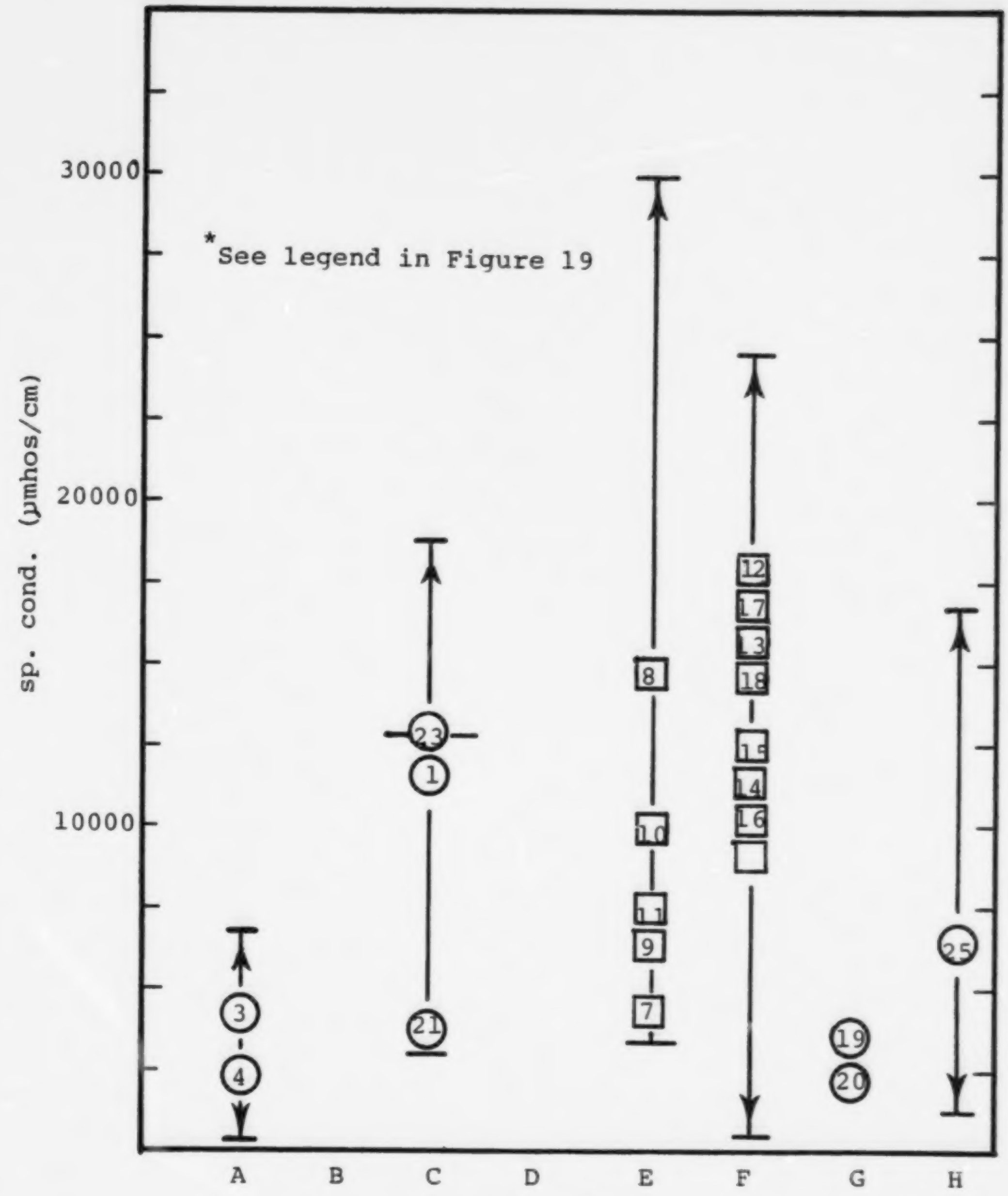


Figure 18. Effect of disposal method on leachate specific conductivity.

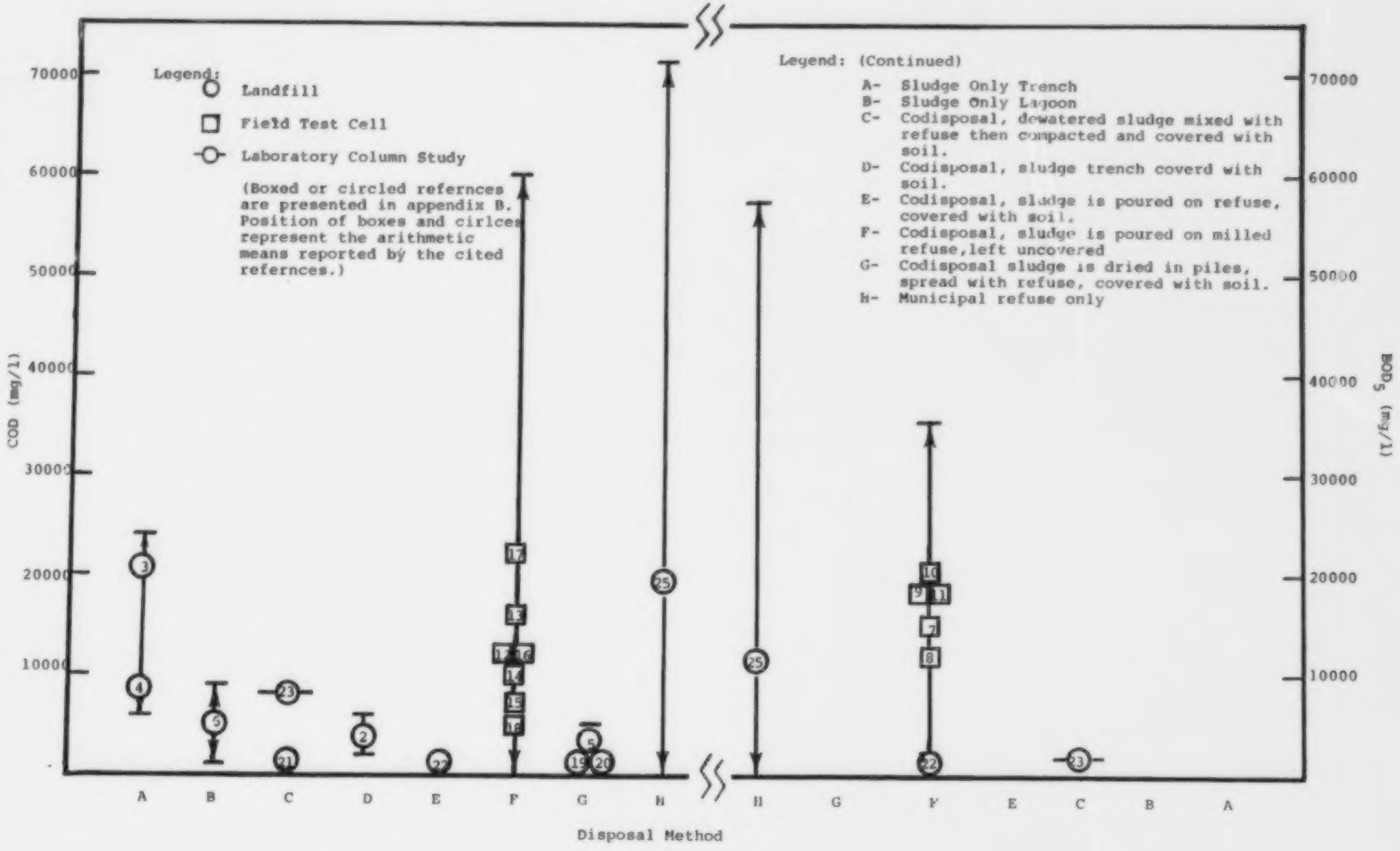


Figure 19. Effect of disposal method on leachate COD.

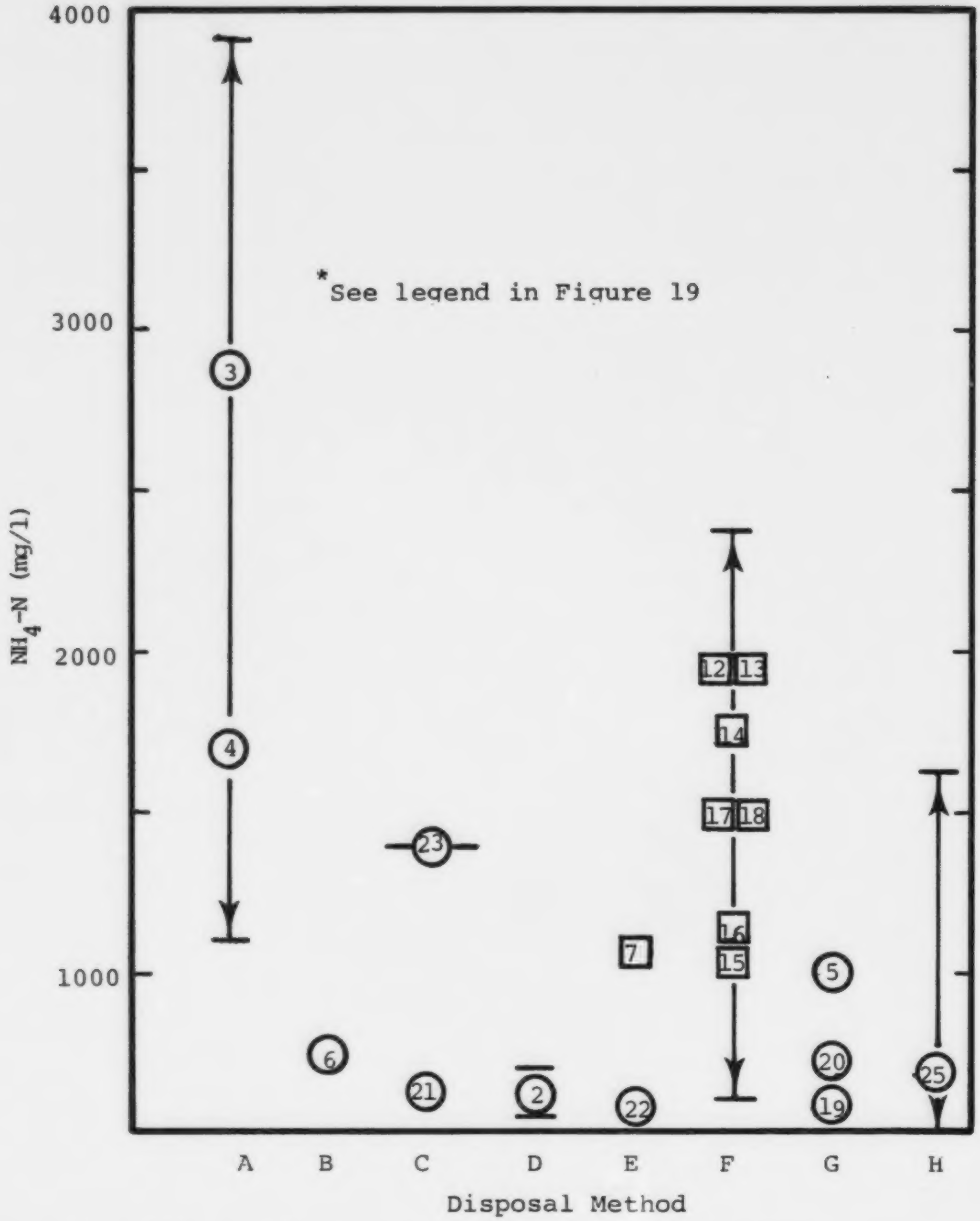


Figure 20. Effect of disposal method on leachate NH_4-N.

sludge-only methods (A and B), codisposal methods (C-G), and refuse-only methods (H). Each specific landfilling technique (A-H) is described in Figure 19. Like the previous figures (Figures 13-16), the range of reported leachate constituent or parametric values is indicated along with the arithmetic mean of values reported by each of the numbered references.

Comparison of leachate pH values among the various disposal methods (Figure 17) shows that the lowest pH (pH=3.7) was reported for landfill method H, which represents refuse-only landfill leachate. Low leachate pH values were also observed for method E (pH=4.5) a codisposal method (liquid sludge is poured on refuse, covered with soil). Landfilling method F, a similar codisposal method, exhibited the highest leachate pH of 9.9. Other codisposal landfilling alternatives and sludge-only methods showed leachate pHs to range between approximately 6.2 and 8.3. The low leachate pH observed for codisposal method E may reflect possible low pH contributions by refuse or high organic acid contributions resulting from anaerobic degradation of raw primary sludge.

Codisposal methods E and F also exhibit high leachate specific conductivity, shown in Figure 18. Methods E and F both involve the application of liquid sludge to refuse. Channeling of the liquid sludge through loosely compacted refuse may account for the high values observed. Mixing of refuse and dewatered sludge, method C is also shown to result in high leachate specific conductivity relative to refuse-only values.

Figure 19 compares COD and BOD_5 levels in leachates for each of the landfilling methods. Mean levels of leachate COD are reportedly high for method A (sludge-only trench, covered with soil), method F (liquid sludge poured on milled refuse, left uncovered), and method H (refuse-only landfills). Leachate BOD_5 levels, though few can be compared, are high for refuse-only (method H) and codisposal (method F) landfills.

Figure 20 shows the concentration of NH_4-N in leachates of the various landfilling methods. Sludge-only trenching method A and codisposal method F show extremely high levels of leachate NH_4-N relative to other sludge and refuse landfilling methods.

Of the sludge landfilling methods evaluated, methods E and F have shown the highest polluting potential for leachate parameters pH, specific conductivity, and constituents COD, BOD_5 and NH_4-N. However, methods E and F also have the most data points in comparison with other landfilling methods.

In summary, a comparison of the leachates of several sludge and refuse landfilling methods show that the highest strength leachates were usually associated with refuse-only landfills and codisposal methods in which liquid sludge was poured atop refuse.

However, these specific codisposal landfilling methods were the source for more data than other codisposal methods and sludge-only methods, which may account for the differences observed.

Sludge/refuse mix ratio--Figures 21-24 show the pH, specific conductivity, and concentrations of COD and NH_4-N in codisposal landfill leachates as a function of sludge/refuse mix ratio. Reported codisposal mix ratios ranged from 1 part sludge to 10 parts refuse (1/10) to 2 parts sludge to 1 part refuse (2/1), all ratios based on wet weight proportions. In each of the figures, the range of reported values is indicated within arrows and the calculated mean is identified by the numbered reference which it represents.

Figure 21 indicates the reported pH values for codisposal leachates of various sludge/refuse mix ratios. Of the paucity of data available, sludge-refuse ratios of 1/5 exhibited the lowest leachate pH (pH=4.5). Higher ratios of 1/1 and 2/1 show leachate pH to range from approximately 5.9 to 9.9, with mean values ranging from approximately 7.5 to 8.0. A slight trend is evident indicating a gradual climb in the upper limit of leachate pH when progressing from low to high sludge/refuse ratios.

Leachate specific conductivity is shown as a function of sludge/refuse mix ratios in Figure 22. The highest leachate specific conductivity is observed for sludge/refuse ratios of 1/5 (29,500 μmhos/cm). Progressing to higher ratios, i.e., 1/1 to 2/1, lowers the maximum leachate specific conductivity below 25,000 μmhos/cm, and mean values to below 20,000 μmhos/cm. The lowest mean specific conductivity values are observed for sludge/refuse ratios of 1/7.

Comparing leachate COD values for the various ratios (Figure 23) reveals a trend of increasing leachate COD when progressing from low to high sludge/refuse ratios. The trend suggests that higher sludge/refuse ratios can lead to higher COD concentrations in leachates. Note, however, that the data for sludge/refuse ratios of 1/5 is based on BOD_5 rather than COD. The high mean BOD_5 concentrations at the 1/5 ratio in comparison to mean COD values contrasts the aforementioned trend.

Figure 24 compares NH_4-N concentrations in leachates of the various sludge/refuse ratios. The highest NH_4-N levels are observed for ratios of 1/1 and higher, though limited data was available.

Summarizing the data presented in Figures 21-24, potential trends linking higher pHs and higher BOD concentrations in codisposal leachates with higher sludge/refuse ratios are evident. More data is needed to qualify such trends, since they are based on limited available data. Specific conductivity and

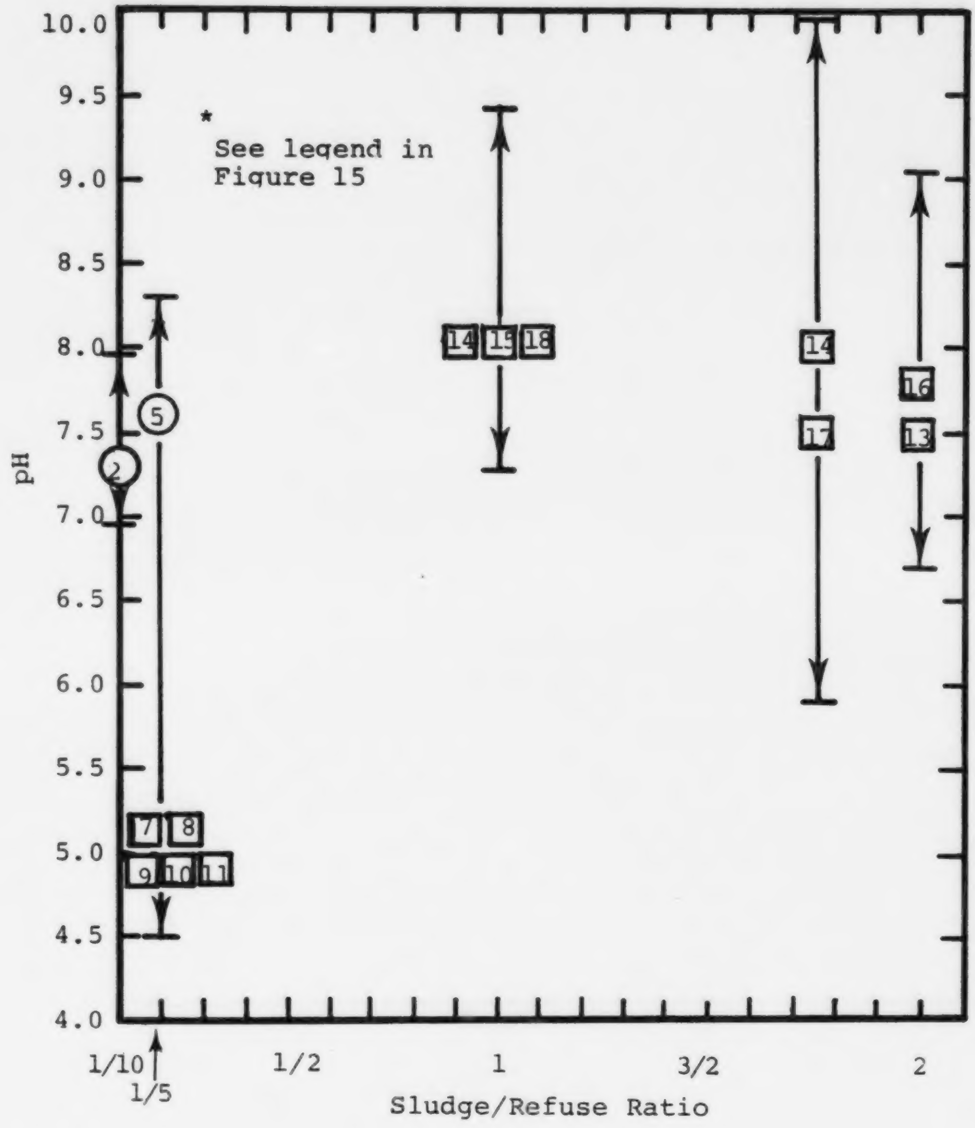


Figure 21. Effect of sludge/refuse ratio on leachate pH.

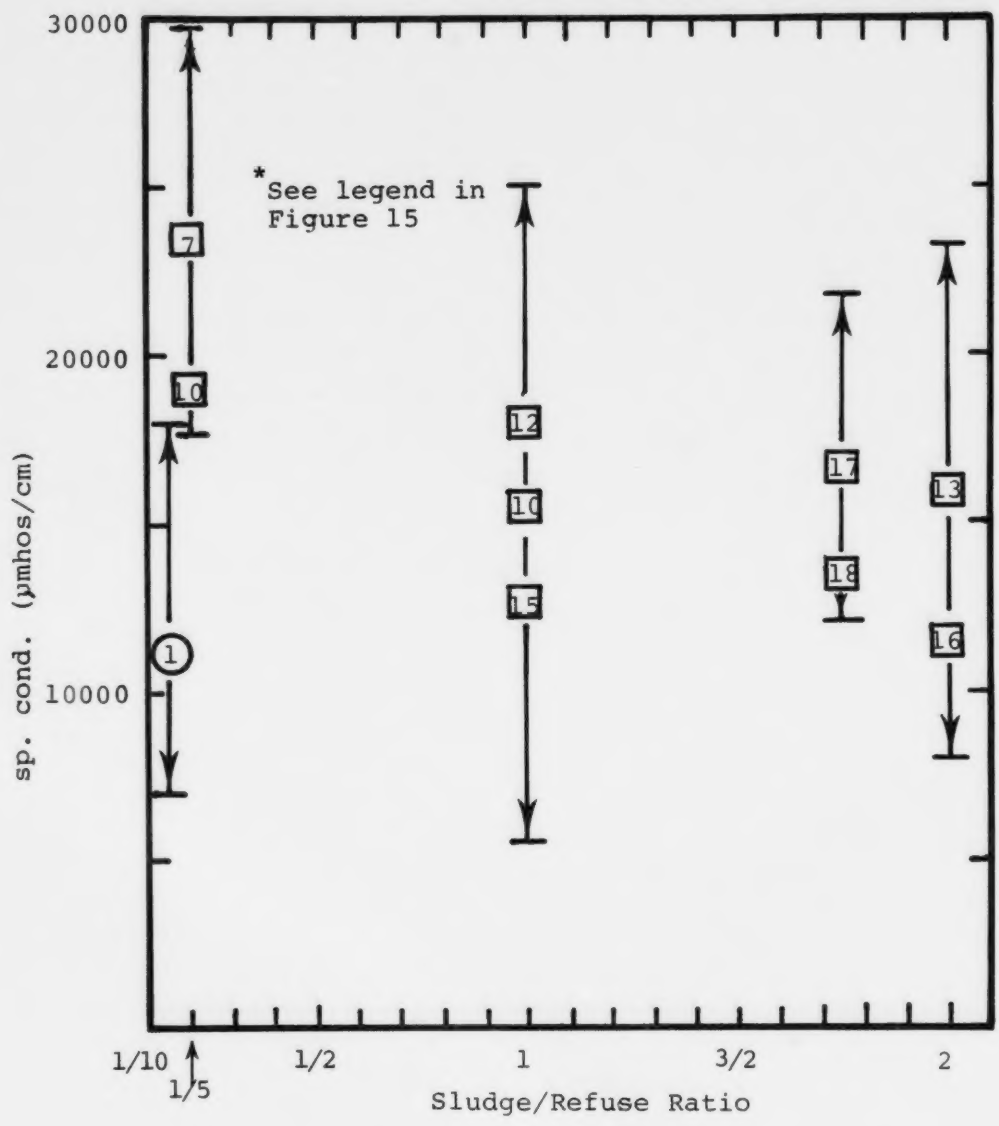


Figure 22. Effect of sludge/refuse ratio on leachate specific conductivity.

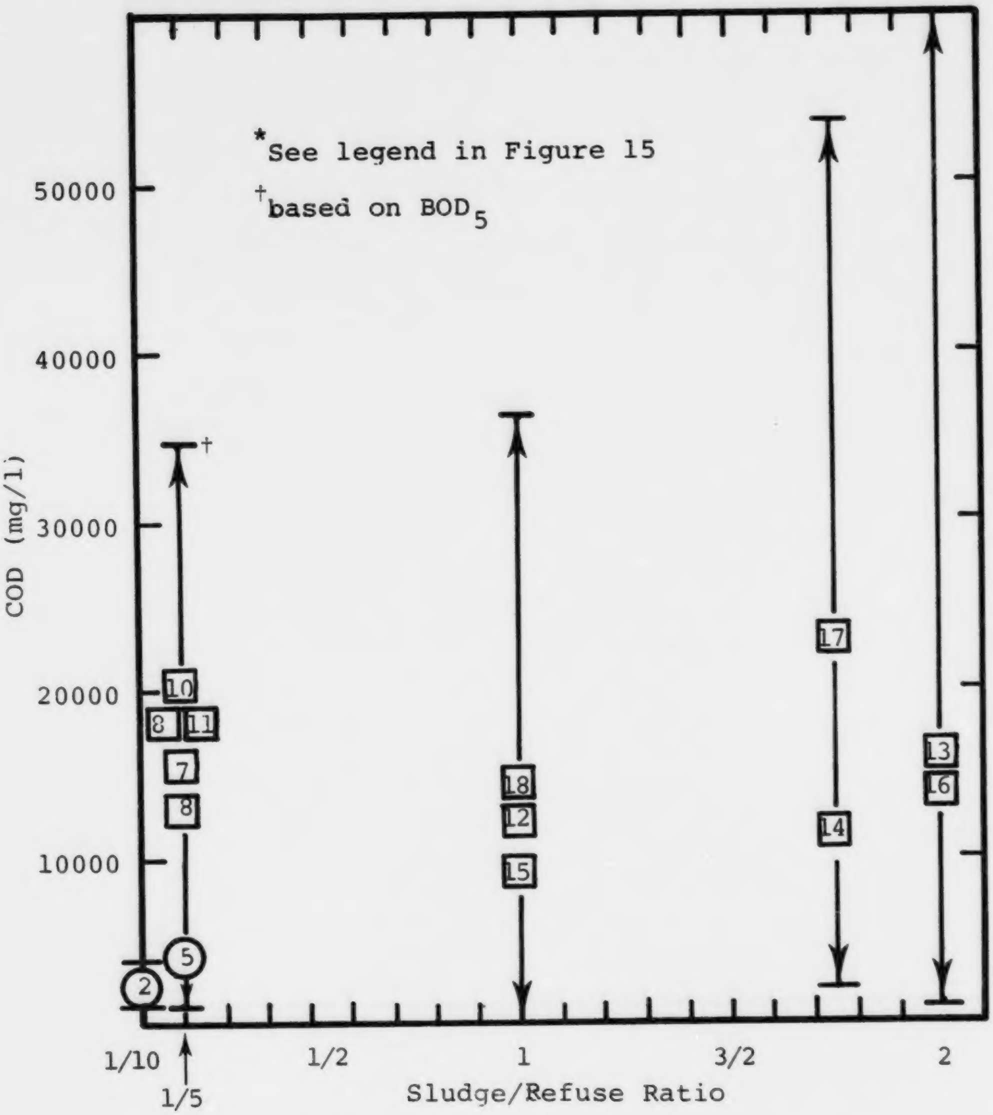


Figure 23. Effect of sludge/refuse ratio on leachate COD.

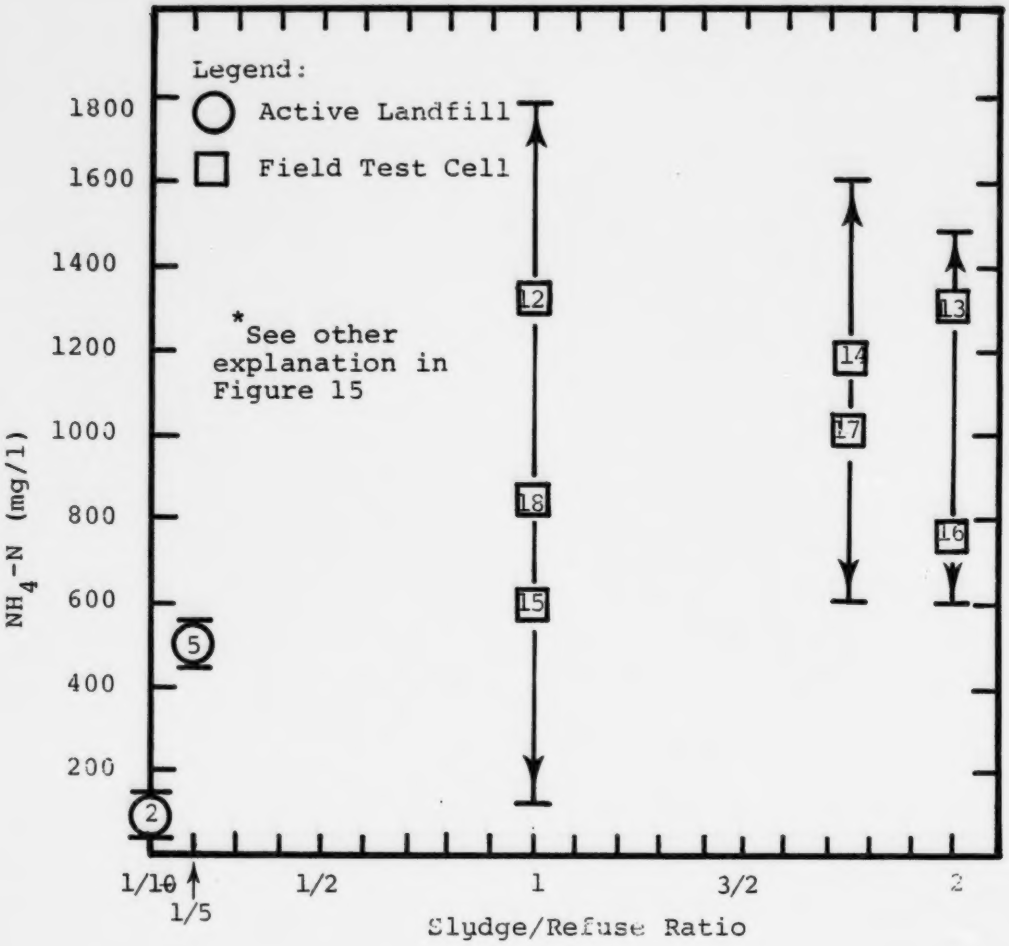


Figure 24. Effect of sludge/refuse ratio on leachate NH_4-N.

concentrations of NH_4-N in leachates of various sludge/refuse codisposal ratios do not suggest any trends.

Age--Sludge age, or the time since sludge placement in a landfill, will influence leachate composition since the mass of sludge contaminants is leached out over a period of time. Sketches were prepared of the changes in leachate pH, specific conductivity, and concentrations of COD and NH_4-N as a function of time since sludge placement. However, all of the data examined was received from either active sludge landfills, field test cells, or laboratory columns. None of the leachate data was representative of an age greater than 2 years, in fact, nearly all of the data represented sludges of 1 year or less. Because of the short time spans involved, no trends were evident from the sketches, and thus they are not presented.

The effects of sludge age on leachate composition have been noted by several investigators. For example, Stone (39) observed BOD_5 concentrations in sludge leachates to peak approximately one year following placement of primary sludge into field test cells. Sikora et al. (83) found that chloride levels in shallow wells within a sludge trench site peaked approximately 18 months after sludge entrenchment; nitrate levels peaked at 30 months after entrenchment.

Summary--Though limited data was available, the composition of sludge landfill leachate is apparently influenced by sludge type, landfilling method, sludge-refuse mix ratio and age. Additional data is needed to give credibility to the apparent trends described.

Runoff Composition

The presence of sludge contaminants in surface water runoff at a sludge landfill site is another source of environmental concern since the runoff could eventually meet a potential source of drinking water, irrigation water, or recreational water. Considerable research has been conducted regarding the quality of runoff from land spreading of sludge, since exposed sludge is susceptible to erosion and release of contaminants to runoff created by rainfall. Landfilling or burial of sludge is expected to diminish the chances for contaminated runoff, provided steps are taken to cover the sludge and minimize on-site sludge storage. A review of literature describing the quality of runoff from sludge amended soils and sludge trenching operations is provided below.

Sikora et al. (83) reported on the quality of runoff from sewage sludge trenching demonstrations in Beltzville, Maryland. Subsurface drainage tiles intercepted runoff and collected it in a pond. Reported maximum concentrations of chloride and nitrate in the drainage tile were 107 mg/l and 32.2 mg/l, respectively; maximum pond water concentrations were 45 mg/l and 19.2 mg/l, respectively. The observed nitrate levels are above the Interim Primary Drinking Water Standards established by the EPA. No standards are set for chloride. It should be noted that the drainage tiles may have intercepted contaminated groundwater flow (83).

In other studies, Brown (121) concluded that surface runoff nitrate concentrations from sludge amended soils depended on the nitrogen concentration of the sludge, plant uptake, nitrification, dentrification, and volatilization. Larson and Dowdy (122) reported that concentrations of Zn, Cu, Cd, Pb, Ni, and Cr in runoff waters from sludge treated soils were low and usually near detection limits with the procedures used. The authors found that small, frequent periods of precipitation cause proportionally larger losses to runoff of sludge borne metals per unit weight of sediment. They also suggest that metal losses in the aqueous phase of surface runoff are likely to be small since only a very small percentage of the total metals are in the soluble form in sludge.

Hinesly and Jones (123) also examined the heavy metal content in runoff from sludge-treated plots. Fe and Mn concentrations in runoff waters from sludge-treated plots were significantly higher than levels in comparable waters from control plots, and exceeded the existing criteria for Fe and Mn in public water sources (0.3 ppm and 0.05 ppm, respectively). Mean total concentrations of both Zn, and Cr in runoff were well within the tolerances for public water sources. Mean total concentrations of Cd (0.003 ppm to 0.008 ppm) sometimes exceeded allowable limits.

With regard to biological contaminants, Walker et al. (124) found that a tile drain intercepting subsurface and surface runoff from a watershed used in sewage sludge trenching studies carried water contaminated with fecal coliforms, but a tile drain intercepting only ground water was essentially free of these organisms. Conversely, Lejcher and Kunkle (125) reported that no fecal coliform bacteria were found in the runoff from the sludge treated plots during the year immediately following application. They concluded that it appeared unlikely that pathogens would survive in the runoff. They felt that limited transfer of microbial cells through the soil profile and rapid die-off of the pathogens in the soil matrix suggested low-risk conditions.

In summary, high concentrations of nitrate, certain heavy metals, and the presence of fecal coliform have been observed in surface runoff from sludge landspreading and entrenchment sites. Surface runoff from sludge landfills poses a significant threat to receiving waters for an improperly managed landfill site. Control measures should be implemented to reduce the risk of contaminated runoff impairing a water resource.

Leachate Volume

Essential to an assessment of the impacts of sludge landfilling upon ground water quality is the consideration of the potential volume of leachate generated. Considerable research has been directed toward a predictive means of estimating the generation of leachate from municipal refuse landfills (126-129), providing the background necessary for the present investigation.

Generally, the systems which govern the volume and flow rate of leachate produced are:

- The quantity and rate of moisture entering the landfill, and
- The retention and transmission characteristics of fill material (i.e., refuse, sludge, and/or soils).

These systems are of dynamic character, and are subject to a variety of familiar natural systems, including climatology, geology, hydrology, geography, and topography. The interaction of these systems in conjunction with landfill operations and disposal methods creates a complex picture of leachate generation, and makes estimating leachate volume a complicated task.

In this section, a simple leachate generation model is presented which through examples, estimates the potential leachate volume generated by sludge-only and codisposal landfills. The effect of locating sludge landfills in various hydroclimatological settings is also addressed. Lastly, important factors affecting the flow of leachate from sludge landfills are identified.

Water Balance Model--

Sludge landfill leachate can be derived from a number of sources, including precipitation, ground water intrusion, sludge moisture, and refuse moisture. Contributions from precipitation include not only on-site incidents, but precipitation in adjacent areas can be channeled onto the landfill site. If waste is placed in or just above the ground-water table, the ground water may saturate the fill material. The contribution of sludge moisture to leachate may result from drainage* upon placement, sludge compaction, or sludge decomposition. Decomposition of refuse may also contribute to leachates. The sources of leachate are outlined in Figure 25.

---

* drainage refers to construction drainage, or the moisture released during and immediately following (within 1 month) cell construction. Pickart (89) reported that the construction drainage of liquid sludge accounted for 8-15% of the initial sludge volume.

Virtually all of the models which have been used for quantitative estimation of leachate volume are derived from the water balance or water budget principle (120). The water balance method is a one-dimensional flow model based on conservation of mass relationships. The generalized water balance relationships are described below. Our concern is the maximum release of leachate for landfills; thus, the time function has been excluded. More sophisticated, computer based models which perform water balance calculations for various operational methodologies of landfills are available (130).

For municipal refuse landfills (120) --

$$Wp = I + R + E \qquad (1)$$

where: Wp= Input water from precipitation (including contributions from surrounding surface runon)

I = Infiltration

R = Surface Runoff

E = Evapotranspiration

Equation (1) illustrates the water balance relationship which occurs at the landfill surface. Precipitation (Wp) will either become surface runoff (R), evapotranspiration (E), or infiltrate (I) into the cover soil. Water which infiltrates the cover soil can act to recharge the dry cover soil or evapotranspirate. Once the field capacity of the cover soil is attained, downward percolation in the soil will occur. The quantity of soil percolation is given as follows:

$$PER_s = I - E - \Delta S_{so} \qquad (2)$$

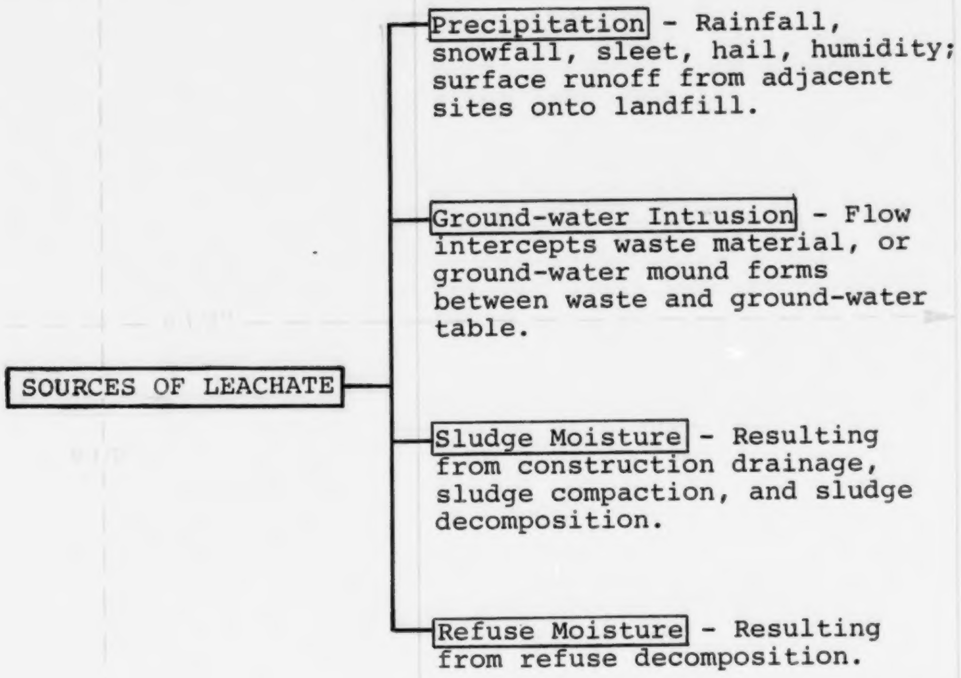
where: PER_s = Percolation in soil

ΔS_{so} = change in moisture storage in soil

Soil percolation will be absorbed by unsaturated refuse. However, once the refuse reaches field capacity, refuse percolate is generated in quantities defined by equation (3) below:

$$PER_r = I - E - \Delta S_{so} + W_{rd} - \Delta S_r \qquad (3)$$

where: PER_r = Percolation in refuse



SOURCES OF LEACHATE

- **Precipitation** - Rainfall, snowfall, sleet, hail, humidity; surface runoff from adjacent sites onto landfill.
- **Ground-water Intrusion** - Flow intercepts waste material, or ground-water mound forms between waste and ground-water table.
- **Sludge Moisture** - Resulting from construction drainage, sludge compaction, and sludge decomposition.
- **Refuse Moisture** - Resulting from refuse decomposition.

Figure 25. Sources of leachate from sludge-only or codisposal landfills

W_{rd} = Moisture contributed by refuse decomposition

ΔS_r = Change in moisture storage in refuse

Barring any ground-water intrusion, PER_r can be re-labeled as leachate. Thus:

$$L = I - E - \Delta S_{so} + W_r - \Delta S_r \qquad (4)$$

where: L = landfill leachate

For Sludge-only Landfills--Equation (4) can be modified accordingly:

$$L = I - E - \Delta S_{so} + W_{sc} + W_{sd} - \Delta S_{sl} \qquad (5)$$

where: W_{sc} = Water contributed by sludge compaction and drainage

W_{sd} = Water contributed by sludge decomposition

ΔS_{sl} = Change in moisture storage in sludge

Equation (5) is essentially the same as equation (4), though refuse contributions to equation (4) have been replaced by sludge in equation (5). Also, water contributed by sludge compaction (W_{sc}) has been added.

For Codisposal Landfills--

$$L = I - E - \Delta S_{so} + W_{rd} + W_{sc} + W_{sd} - \Delta S_r - \Delta S_{sl} \qquad (6)$$

Equation (6) merely combines equations (4) and (5).

Applying the Water Balance Model--

Applying the water balance model to sludge-only and codisposal landfills requires quantification of variables in equations (5) and (6), respectively. The use of the water balance model as a predictive tool for potential leachate production is illustrated in the following hypothetical examples.

For Sludge-only Landfills--Given a 20 hectare (approximately 50 acres) sludge-only landfill located in a geographical area of the United States where the average yearly evaporation is equivalent to infiltration (E = I), what is the potential volume of leachate producible? Assume a nominal landfill depth of 7.5 m (25 ft)*, and that approximately 1.5 million metric tons (1.65 million tons) of raw primary sludge of an initial 25% solids content have been placed.

---

* assuming the specific gravity of sludge = 1

Equation (5) presents the water balance equation for sludge-only landfills. A comprehensive review of the methods which may be used to quantify the variables common to both sludge-only and refuse landfills, i.e., infiltration (I), evaportranspiration (E), and the change in moisture storage in soil ΔS_{so}, is provided by Lu et al. (120). For simplicity, however, we have assumed that E = I. We also assume that the soil moisture never exceeds field capacity, so that ΔS_{so} can be eliminated from further consideration. Therefore, potential leachate contributions from infiltration have been eliminated, and equation (4) can be modified as follows:

$$L = W_{sc} + W_{sd} - \Delta S_{sl} \qquad (7)$$

Experimental work performed by the Los Angeles County Sanitation District (LACSD) (37) provides the information necessary to estimate the moisture released by sludge as a result of compaction (W_{sc}) and decomposition (W_{sd}) processes. The effects are illustrated in Figures 26 and 27. These figures provide estimates of the leachate producible from sludge landfills of various nominal depths as a function of sludge solids content. Safety factors have been included which tend to overestimate the dewaterability of the sludge.

Figure 26 illustrates the leachate release resulting from sludge compaction (W_{sc}). The estimates are based on differences in sludge moisture before and after surcharge loads (equal to the indicated depths) were applied. In reference to our example, the graphs reveal that the leachate produced by a sludge of 25% solids from a landfill of 7.5 m (25 ft) nominal depth is approximately 1200 liters per 1000 kg of dry sludge solids. This is equivalent to 300 liters per 1000 kg of wet 25% solids sludge. For a landfill containing 1.5 million metric tons, or 1.5×10^9 kg, of wet 25% solids sludge, the loss of entrained water from sludge compaction (W_{sc}) equals approximately 450 million liters (103 million gallons). The sludge loses more than half of its entrained water and the solids content is increased to 35%.

Figure 27 is similar to Figure 26, but depicts the ultimate leachate production from landfills of various nominal depths as a function of sludge solids content. The graphs here reflect the additional contribution to leachate from sludge decomposition (W_{sd}) and heat treatment resulting from decomposition processes. LACSD found that elevated landfill temperatures resulting from sludge decomposition could enhance dewaterability (37). Water released through biological degradation represents an estimated destruction of 1/3 of the sludge solids (37). This degree of degradation represents a 50% over-estimation of the ultimate biodegradability of sludge following its initial digestion for 15-20 days at mesophilic temperatures (approximately 75°C). Figure 27 shows that for a sludge of 25% solids in a landfill 7.5 meters deep, the ultimate leachate production is

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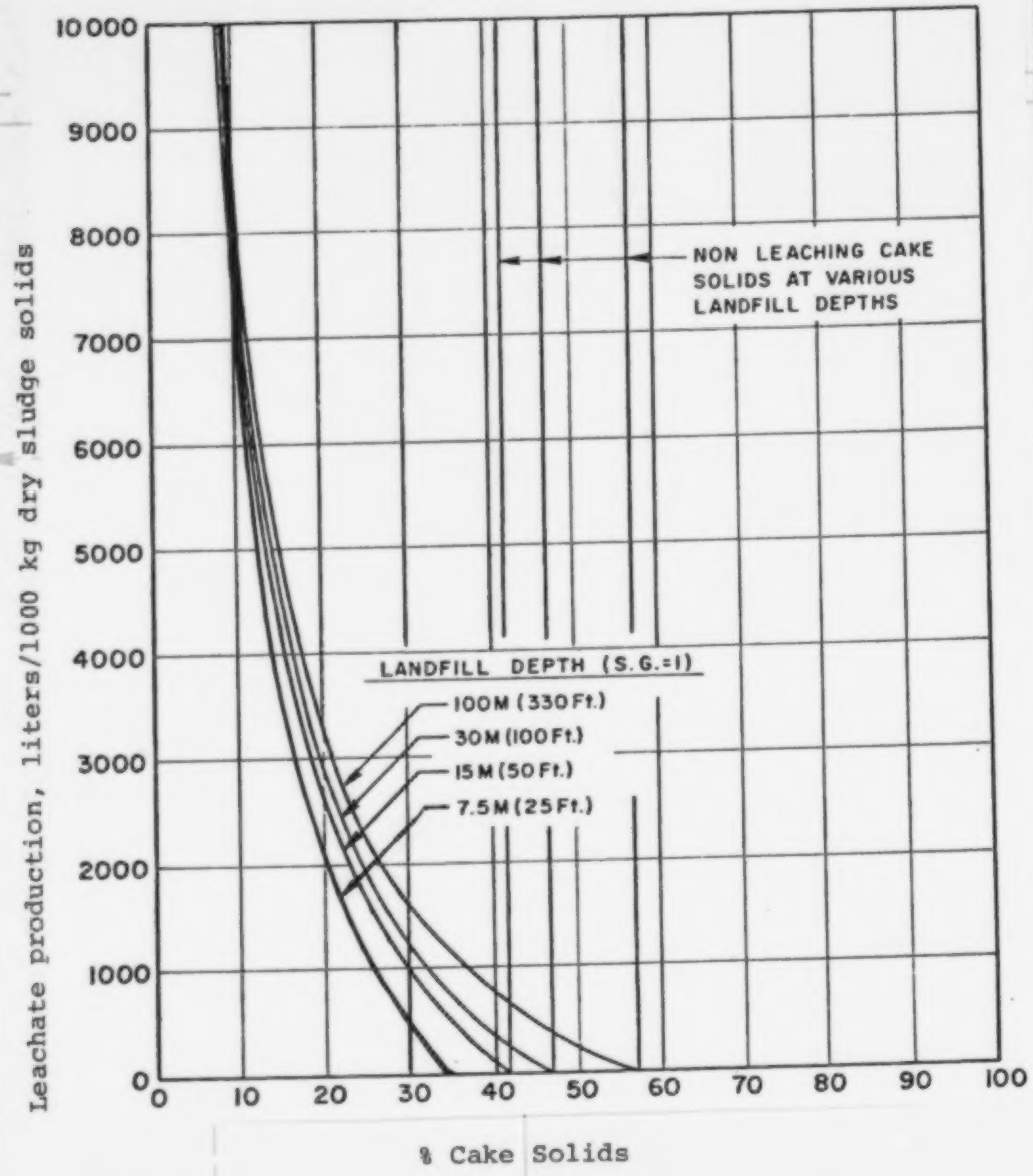

Figure 26. Leachate production resulting from sludge compaction (37).

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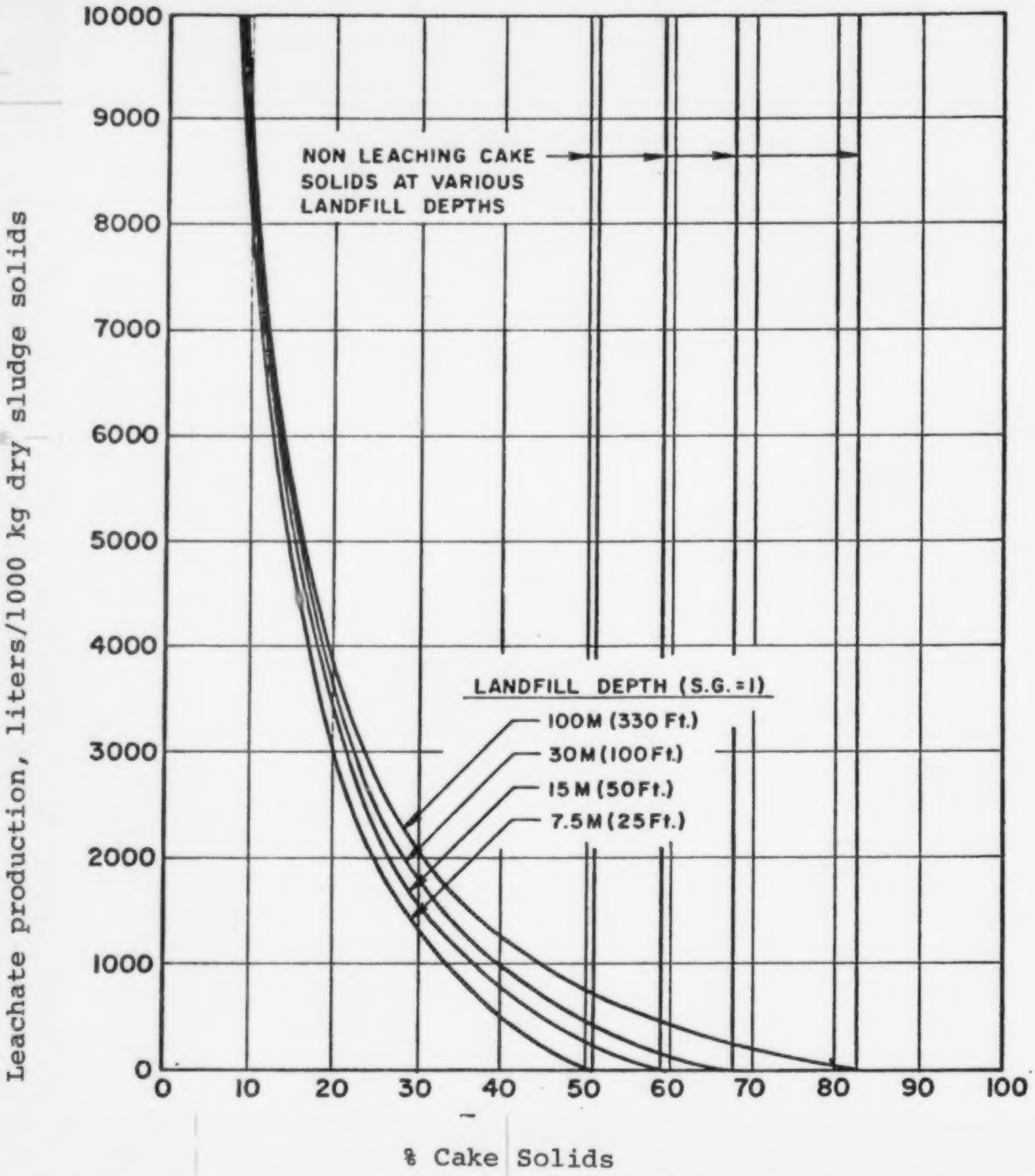

Figure 27. Leachate production resulting from sludge compaction and decomposting (37).

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approximately 2000 liters per 1000 kg of dry sludge solids. This is equivalent to 500 liters per 1000 kg of wet 25% solids sludge. For our hypothetical landfill containing 1.5×10^9 kg of wet sludge solids, approximately 750 million liters (171 million gallons) of leachate are ultimately producible. The moisture released through decomposition processes, including heat treatment, represents approximately 40% of the ultimate leachate producible.

The final factor influencing the leachate production from our hypothetical landfill is the change in moisture storage in sludge (ΔS_{sl}). The capacity for dewatered sludge to store moisture has been shown to be a function of initial sludge solids content, landfill depth, and sludge age (37). Though unconfirmed in literature, it is speculated that highly dewatered sludges (e.g., sludges >30% solids content) are not at field capacity. That is, dewatered sludges are able to retain limited amounts of added moisture before continuous downward percolation occurs. Moisture retention by sludges has been observed by Swartzbaugh _et al_. (38) and Stone (39) in landfill simulation experiments. Also, sludges have been observed to dewater from top to bottom in trenches, and thus the drier upper layers are amenable to water retention. The effects of landfill depth or surcharge loads, however, will limit water retention due to sludge compaction. Regarding age effects, LACSD reports that the degradation of sludge within a landfill can depress their water retention capability below that observed for fresh sludge (37). The combination of these individual factors into a quantifiable definition of moisture retention by sludges has not been accomplished.

For our present example, moisture retention can be considered insignificant in comparison to the volume of moisture released. The value of ΔS_{sc} cannot be negative (which would signify moisture release) because the moisture released by the sludge has already been attributed to sludge compaction (W_{sc}) and sludge decompositoin (W_{sd}).

Thus, the total volume of leachate producible from our hypothetical landfill is 750 million liters, or 171 million gallons.

For codisposal landfills--Given a 20 hectare (approximately 50 acres) codisposal landfill under identical climatological circumstances as those presented in the previous example (i.e., evaporation (E) = infiltration (I)), what is the potential volume of leachate producible? Assume a nominal landfill depth of 7.5 m (25 ft)*, a mix ratio of 4:1 (refuse:sludge), and a raw primary sludge of an initial 25% solids content. Assume there are 0.4 million metric tons (0.44 million tons) of sludge and 1.2 million metric tons (1.32 million tons) of household refuse in the landfill which have been thoroughly mixed prior to placement.

---

* specific gravity = 1

The potential leachate producible from a codisposal landfill is given by equation (6). Assuming as we did for sludge-only landfills that soil moisture never exceeds field capacity (ΔS_{sc} can be eliminated from further concern), i.e., water contribution from infiltration is absent, equation (6) can be modified accordingly:

$$L = W_{rd} + W_{sc} + W_{sd} - \Delta S_{r} - \Delta S_{sl} \qquad (8)$$

Microbial decomposition of the biodegradable organics in refuse generates water (W_{rd}), which will contribute to landfill moisture and leachates. The extent and rate of microbial activity and subsequent water generation depends primarily on the amount and pH of refuse moisture, temperature, the presence of oxygen, and the composition and particle size of the refuse (131-133). Presently available information can only give a rough estimate of the rates of refuse degradation and water generation (120). Research conducted by the California State Water Pollution Control Board (134) found that ultimate water production from refuse (compacted) decomposition was approximately 0.006 l/m^3 (0.0014 gal/m^3). Given 1.2 million metric tons of refuse per our example, the water produced by decomposition is approximately 7200 liters (1634 gallons).

The ultimate leachate producible through sludge compaction (W_{sc}) and sludge decomposition (W_{sd}) can be computed from Figure 27. For a sludge of 25% solids content and a landfill depth of 7.5 m (25ft), the ultimate leachate producible is approximately 2000 liters per 1000 kg of dry sludge solids. This is equivalent to 500 liters per 1000 kg of wet 25% solids sludge. Note that safety factors have been included in Figure 27 estimates which tend to slightly over-estimate leachate production due to sludge decomposition. For our example, 0.4 million metric tons (400 million kg) of wet 25% sludge solids can produce approximately 200 million liters (45 million gallons) of leachate.

Because of its absorptive capacity, municipal refuse has the ability to delay or possibly prevent a codisposal landfill from reaching field capacity. Figure 28 displays the initial and final leachate absorption capability for 1000 kg of "as received" City of Los Angeles' household refuse, as developed by LACSD (37). The landfill depths indicated are nominal (assuming the specific gravity = 1). The fully decomposed refuse curve illustrates a 25% loss of absorptive capacity at shallow depths and 16% at very deep sites (37). Hence, degradation does not alter the overall ability of refuse to retain water. Because we are interested in ultimate leachate production, the fully

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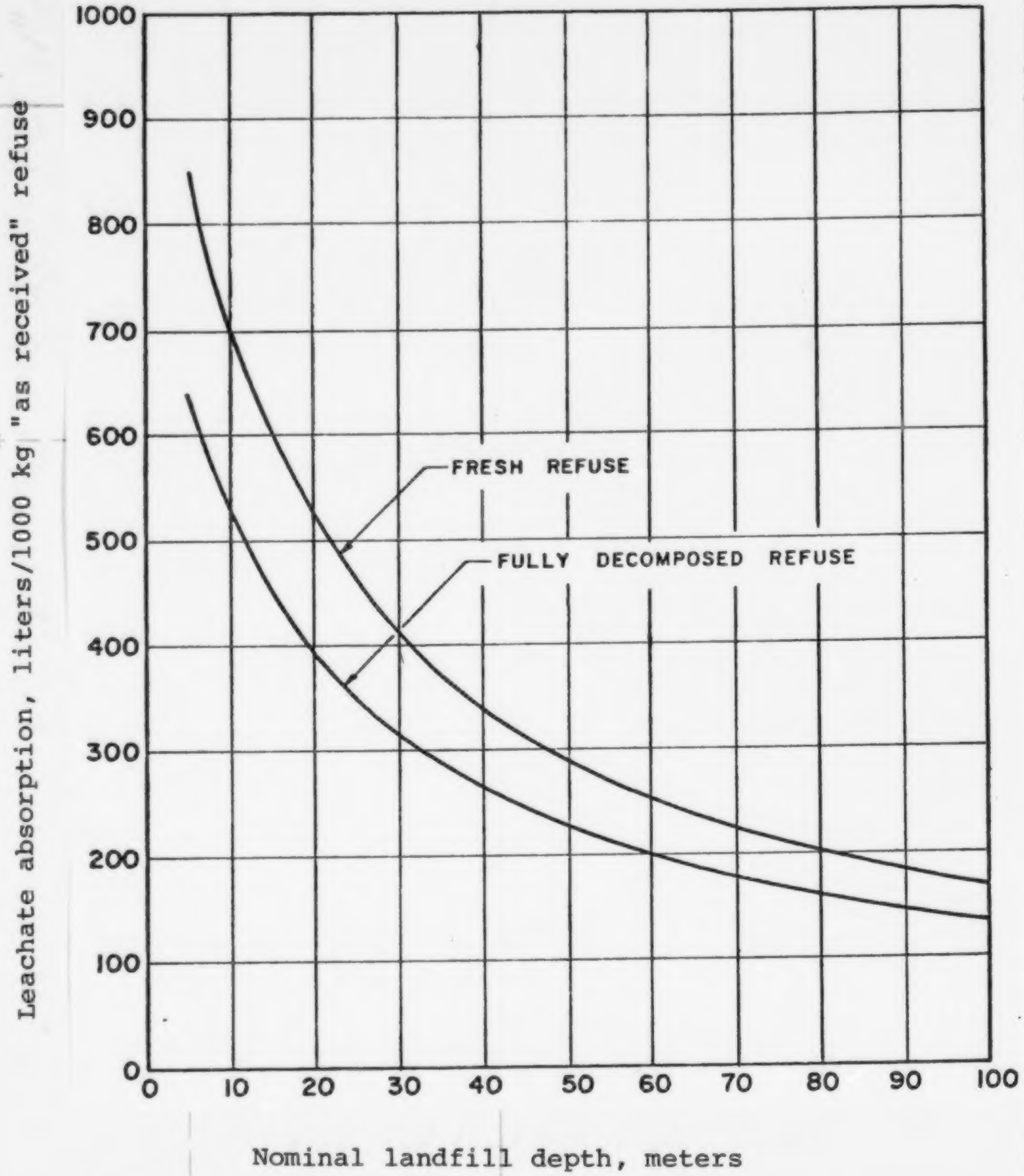

Figure 28. Initial and final leachate absorption capacity for household refuse (37).

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decomposed refuse curve will serve as the basis for our calculations. The ultimate leachate absorption by refuse for a landfill 7.5 m (25 ft) deep is approximately 600 liters per 1000 kg of "as received" refuse. Given 1.2 million metric tons or 1.2×10^9 kg, of "as received" refuse, approximately 720 million liters (163 million gallons) of moisture can be absorbed before the refuse reaches field capacity.

The final factor influencing leachate generation by co-disposal landfills is the change in moisture storage in sludge (ΔS_{sc}). Because moisture retention by sludge can be considered negligible in comparison with the volume of moisture released, ΔS_{sl} can be eliminated from consideration.

Substituting the values derived in discussion for each of the variables in equation (8) we get:

$$\begin{aligned} L &= 7200 \text{ liters} + 200 \text{ million liters} - 720 \text{ million liters} \\ &\cong -520 \text{ million liters} \end{aligned}$$

Thus, refuse effectively absorbs all leachate and moisture generated by the fill materials of our hypothetical landfills, and retains the capacity to absorb an additional 520 million liters (118 million gallons) of moisture prior to reaching field capacity.

LACSD used the information from Figure 28 to determine the maximum ultimate non-leaching sludge/refuse wet weight ratio as a function of sludge solids content at various landfill depths. This relationship is illustrated in Figure 11. Like the previous diagrams developed by LACSD, i.e., Figures 26-28, the following assumptions and safety factors have been included where applicable (37):

- Los Angeles County type refuse is employed;
- Sludge decomposition is assumed to proceed to 50% greater extent than available data suggests;
- The actual surcharge load exerted on the refuse and and sludge mixture will decrease a substantial amount due to conversion of solids to methane and carbon dioxide; and
- The absorption capacity of the cover material, which can be significant, is not considered.

Unlike Figures 26-28, the following additional assumptions have been made for Figure 11:

- A daily cover material (2 grams per cubic centimeter bulk density) is assumed to be disposed on a 1:3 cover to refuse and sludge weight ratio;

- Nominal landfill depths are not employed but have been converted to actual landfill depths.

Figure 11 illustrates the large dependence of the maximum non-leaching sludge to refuse ratios on the depth of the disposed mixture. Whereas variations in landfill depth bring about marked changes in the ratios, slight variations in initial solids content have minor effect on the ratios.

Hydro-Climatological Effects--

The previous examples have shown that a major portion of the sludge mass is water which can be squeezed from the sludge under landfill surcharge loads. Sludge decomposition processes can enhance sludge dewatering and add to leachate production. In each of the previous examples, however, we have assumed that the effects of evaporation essentially prevented infiltration to the landfills. This can be a reasonable assumption for some areas of the United States, but for others, infiltration will exceed evaporation or visa-versa. These efforts can significantly influence leachate volume generated.

Figure 29 presents an estimate of the average annual net infiltration for the continental United States. The figure was constructed using mean annual precipitation and evaporation information, plus an estimate of the potential surface runoff for the respective areas. Note that Figure 29 is merely an estimate of annual net infiltration and not empirically derived. True measures of infiltration for a particular areas should be determined experimentally. The principle function of Figure 29 is its use as a comparison of the potential landfill infiltration rates for the continental United States.

Figure 29 shows the potential for annual net infiltration for the northwestern, northeastern, and portions of the mid-eastern and southern United States. Thus, the potential for infiltration to contribute to, or provide the source for, leachates from landfills in these areas is the greatest. Specificially, these potential problem areas include the states of Washington, Oregon, the northern portion of California, Maine, New York, West Virginia, southwestern Virginia, Tennessee, North Carolina, Connecticut, Rhode Island, Massachusetts, New Hampshire, Vermont, New Jersey, Pennsylvania, southern Ohio, southern Indiana, Kentucky, northern Georgia, southern Illinois, southeastern Missouri, northwestern Alabama, and northeastern Arkansas (120).

For areas with sub-zero net annual infiltration, excessive precipitation from storm events can lead to infiltration. The volume of infiltration should be estimated on a case by case basis, using information on the duration of precipitation, evapotranspiration, cover soil permeability, and surface runoff.

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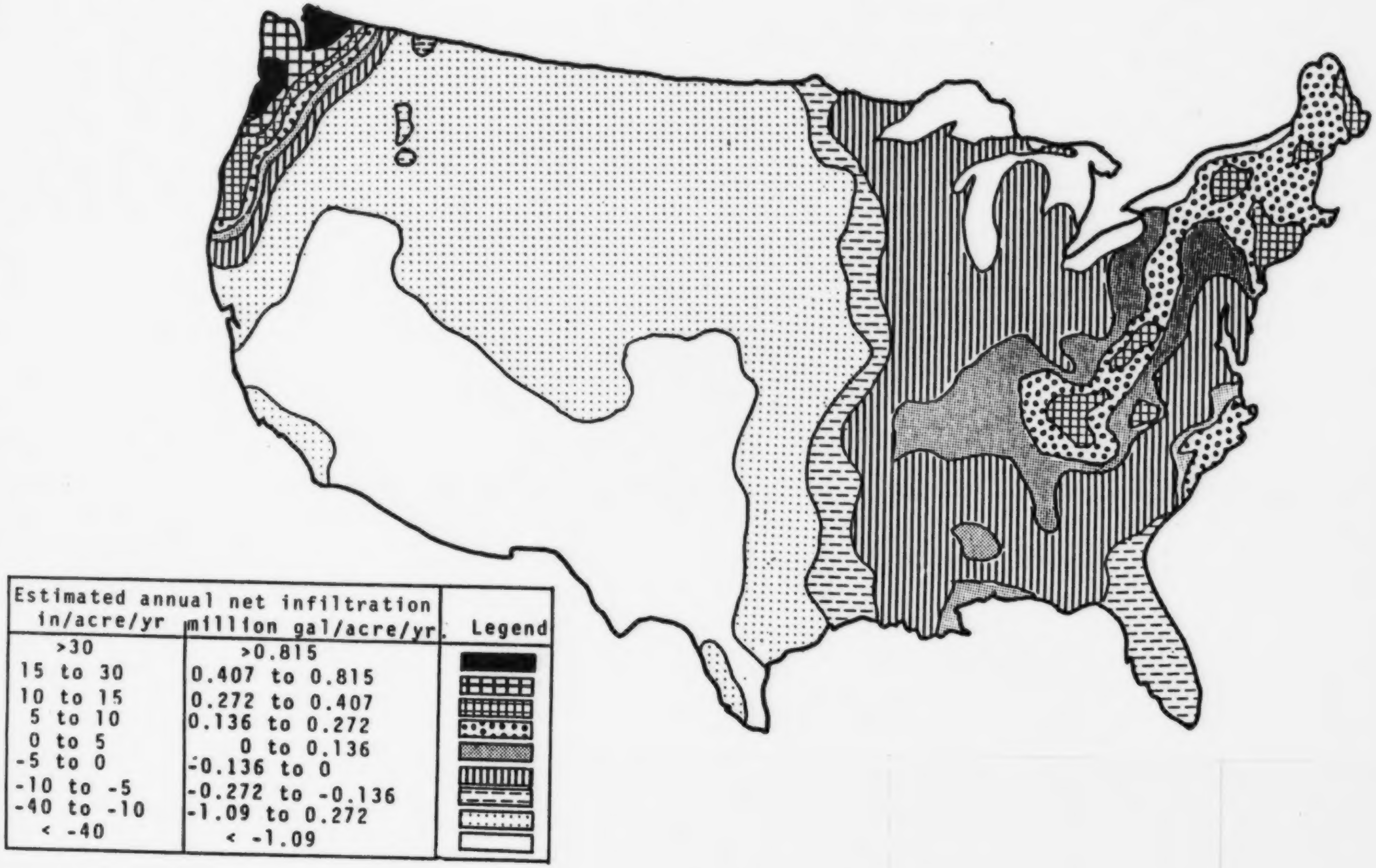

Estimated annual net infiltration in/acre/yr	Estimated annual net infiltration million gal/acre/yr.	Legend
>30	>0.815	■
15 to 30	0.407 to 0.815	▦
10 to 15	0.272 to 0.407	▥
5 to 10	0.136 to 0.272	⁘
0 to 5	0 to 0.136	▒
-5 to 0	-0.136 to 0	▥
-10 to -5	-0.272 to -0.136	▤
-40 to -10	-1.09 to 0.272	░
< -40	< -1.09	☐

Figure 29. Potential annual net infiltration of the continental United States (120).

Rate of Leachate Production--

The rate of leachate production is important to operational aspects such as collecting, handling, and treatment. As mentioned previously, construction drainage can be an important operational constraint. Produced during or immediately following cell placement, construction drainage is the first substantial quantity of liquid released from a site.

For sludge-only landfill sites, the early stages of consolidation (e.g., 0-50 days) can produce significantly greater quantities of leachate than later stages. Generally between 65 and 90% of "primary consolidation" settlement takes place within one year (135), thus releasing the greatest proportion of endogenous sludge water. Secondary compression, resulting from sludge decomposition, will generate at an indeterminate rate according to the source of leachate. However, the volume of leachate generated by secondary compression will be less than primary consolidation settlement (135).

In general, for codisposal landfill sites, sludges of higher moisture content will be the first to produce leachate. Pickart (89) found codisposal test cells of 70 and 55% initial moisture content to initially produce leachate at one and four months, respectively. Refuse-only cells did not produce leachate.

Summary--

Using a simple leachate generation model, it has been shown that large volumes of leachate can be produced by raw primary dewatered sludge as a result of landfill surcharge loads and decomposition processes. Because of important effects of landfill depth and sludge moisture on sludge leachate production, efforts to minimize leachate production should be directed toward the following:

(1) For sludge-only landfills, sludges should be stabilized and dewatered prior to landfilling. Appropriate stabilization alternatives include those processes which can reduce the readily biodegradable organic content of sludges, i.e., anaerobic and aerobic digestion processes. By reducing the volatile organic content of the sludge, water released through biodegradation processes can be reduced. For landfills of depths greater than approximately 5 m, a high degree of sludge dewatering is recommended (i.e., sludge solids content should exceed 30%) to prevent leachate production from sludge compaction.

(2) For codisposal landfills, sludge/refuse mix ratios should be maintained which can prevent the landfill from exceeding its field capacity. Figure 11 can be used as a guide in this respect.

Infiltration can contribute significantly to leachates, particularly in areas where precipitation exceeds evaporation. Such critical areas include the northwest, northeast, midwest, and southern portions of the continental United States. Rates of leachate production from sludge compaction processes appear greatest in the first year following placement. Decomposition processes will produce water at comparatively reduced rates.

Surface Water Runoff Volume

Surface water runoff volumes on or adjacent to a landfill site can be determined by surface measurements, empirical formulas, graphic methods, and water balance equations. A comprehensive review of each method is provided by Lu, et al. (120). It is beyond the scope of this report to describe the methods used to quantify surface water runoff. In general, surface water runoff can contribute significant volumes of water to receiving waters and are thus a primary concern in landfill operations. Landfill operations should contain all surface water runoff to mitigate the risks of contaminated runoff entering water resources.

IMPACTS ON AIR QUALITY

Sludge landfills can be the source of hazardous and noxious gases, including methane, hydrogen sulfide (H_2S), sulfur dioxide, ammonia, methymercaptans, methyl sulfides, amines, indole, and skatole (136). The major air quality impacts associated with sludge landfilling include noxious odors, aerosol hazards, dust, noise, and fire hazards. Each of these impacts are assessed in this section. Also included is a discussion of the rates of production of gases from sludge landfills and the factors influencing the production of methane.

Potential Impacts

Studies on potential air quality impacts caused by sludge landfills are lacking. Based on peripherally related information and scientific judgement, the major effects are described below.

Odors--

Odor can be a common and serious problem at sludge disposal sites unless remedial steps are taken. Odors associated with sludge can be attributed to hydrogen sulfide, ammonia, mercaptans, methyl sulfides, amines, indole and skatole (136). Strong odors are normally encountered for unstabilized sludges of less than 30% solids content (8). The EPA Process Design Manual for Sludge Treatment and Disposal (8) suggests that unless it is stabilized to non-reactive levels (<50 by weight), the biodegradable volatile organic material of wastewater solids will continue to decompose if the moisture content is too high (solids content <30%). This decomposition will reduce organic material and generate gaseous byproducts. Depending on the stage and sometimes the type of stabilization employed prior to dewatering, the method of conditioning for dewatering, and the dewatering method itself, gaseous byproducts may or may not be odorous. For example, aerobically stabilized dewatered sludge would be more subject to strong odors than anaerobically stabilized dewatered sludge; polymer-conditioned dewatered sludge would be more subject to strong odors than lime and ferric conditioned dewatered sludge; and centrifuged dewatered sludge would be more subject to strong odors than vacuum filtered dewatered sludge (8).

Dust and Aerosols--

Dust is usually caused by haul vehicles and equipment moving along on-site dirt roadways. Dust poses a health risk for individuals with respiratory ailments, or eye discomfort for the general public. Effects of aerosols generated by sludge landfilling operations are undocumented. However, it has been determined that airborne bacteria and virus-containing particles may be generated from sewage treatment plants and spray irrigation operations (137-141). Therefore, the application and discharge of WWTP sludge at landfill sites may be a source of viable pathogenic aerosols. An evaluation of the risks of pathogenic aerosols is presented in Section 6, Public Health Effects.

Noise--

Noise will occur from equipment operating at the landfill as well as from haul vehicles. The Process Design Manual for Municipal Sludge Landfills (28) indicates that area fill mound sludge/soil codisposal operations generally require more on-site equipment than other landfilling methods and therefore pose greater potential noise impact to surrounding communities. Generally, the noise of landfill operations is similar to other heavy construction activity. Noise impacts can be minimized by routing haul traffic through the least populated areas. Further, the use of earthern berms and trees can effectively mitigate the effects of landfill noise in nearby neighborhoods.

Fire Hazards--

Methane is highly explosive when it accumulates in concentration of 5 to 15% in air (142,143). If sufficient dilution by air is not provided or if methane moves through the soil and accumulates in nearby structures, fire hazards may exist.

Methane migrating through the sides or top of sludge landfills may adversely affect plant life. Where disposal sites are located next to planted areas, or where parks and recreational areas are planned after disposal operations cease, the effect of methane on plant health is of particular concern.

Gas Composition and Rates of Production

Investigations of sanitary landfills have revealed municipal refuse to decompose under initially aerobic conditions and then under anaerobic conditions as oxygen is exhausted.

Like sanitary landfills, carbon dioxide and methane comprise as much as 90% of the gases produced at sludge/refuse codisposal sites (39). Studies have suggested that CO_2 concentrations are highest shortly after waste placement and covering (39,144). As the fill ages and decomposition progresses, CO_2 concentrations decrease and level off, whereas CH_4 concentrations tend to increase and level off. Stone's data indicate that methane levels peak and plateau at approximately 600 days for sludge/refuse mixtures of approximately one to five (39). Figure 30 presents a qualitative indication of the relative rates of CO_2 and methane production.

Increasing amounts of raw primary sludge in sludge/refuse mixtures may lead to a corresponding increase in the rate of methane production. The higher concentration of organics represented by increased amounts of sludge have the potential to increase the volume of methane produced. Stone found methane to comprise up to 40% of the total volume of gas released at various depths of sludge/refuse test cells (39). Stone also observed increased production of hydrogen sulfide gas from those test cells containing admixed raw sewage as compared to refuse-only cells. Concentrations ranged from trace levels to 750 mg/l for codisposal cells, whereas municipal refuse cells were limited to a maximum of 25 mg/l, at various cell depths.

Volatilization of organic constituents can occur at sludge landfill sites during sludge storage, handling, and final disposal. The vaporized contaminants of most concern, due to their toxicity, are the halogenated organics and aromatic hydrocarbons. Except for pesticides, available information on the volatilization of these compounds is limited. Spencer and Claith (145) have suggested that volatilization of surface deposits and soil-incorporated pesticides plays a significant role in the dissipation of pesticides from solid surfaces. The potential volatility of pesticides and other organics is related to the inherent vapor pressure of the compound, but the actual volatilization rate will depend upon environmental conditions. Shen and Tofflemire (146) suggest that at least a 99% reduction in volatilization can be permanently achieved by a low permeability topsoil cover (e.g., liner, clay, etc.).

Factors Influencing Methane Production

Various factors can impact the production of methane from

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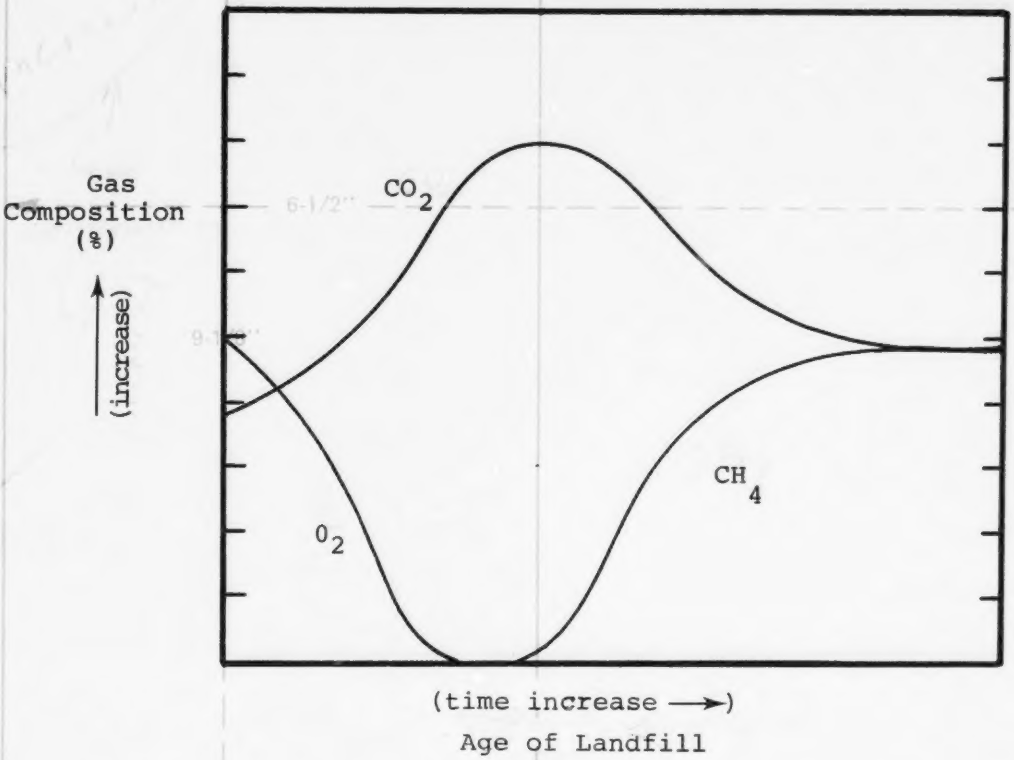

Figure 30. Theoretical gas production curves for sludge landfills.

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sludge landfill sites. These factors can be summarized as follows:

Moisture--
The initial moisture content of the sludge or sludge/refuse mixtures may have a marked effect on the rate of decomposition and methane production. Studies have shown that higher landfill moisture levels produce higher rates of methane production (144,147). However, total lifetime methane generation will be the same as that encountered at lower moisture levels and production rates.

Temperature--
Gas production is accelerated by higher temperatures, up to a certain limit. Initial high temperatures observed in recently constructed landfills correspond to aerobic conditions and little or no methane will be liberated (134). However, following stabilization, anaerobic conditions prevail, and methane is produced. High temperatures can promote rapid stabilization and thus accelerate methane formation.

Shredding--
The effects of admixing WWTP sludge and shredded refuse upon gas production has not been studied. However, shredding substantially increases the surface area of degradable refuse, promoting more rapid biodegradation and increased rate of methane production (148,149,150). The addition of sludge to shredded municipal refuse will have a more pronounced effect on methane production in comparison to shredded refuse alone, due to increased moisture content, organic matter, and bacterial population of the admixture.

Age--
Fungaroli (148) reports maximum methane production to occur in refuse landfills during the second and third year. While local increases in methane occurred toward the end of the fifth year, generally less methane was available. The general trend of concentrations was shown to decrease with time.

pH--
A pH between 6.5 and 7.5 is optimum for methane gas production (151).

Literature has not reported attempts at gas recovery at sludge landfills and it may not be feasible for smaller landfills (12). In order for methane recovery at refuse landfills to be feasible, the landfills must be very large, e.g., more than 5,000,000 metric tons (approximately 5,500,000 tons) of refuse are generally required (147).

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IMPACTS ON LAND QUALITY

Landfilling of sludge may be constrainted by a number of land or soil related impacts. Among these include:

- Certain disposal areas may be particularly sensitive to ground-water contamination from leachates, or may provide a habitat for rare wildlife;
- Clearing of land necessary for landfill construction or daily operation may accelerate erosion; and
- Surrounding soils may accumulate high concentrations of contaminants from the landfill site making the soil unfit for most future beneficial uses.

This section will define those areas considered sensitive to sludge landfilling practices and review other land related impacts.

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Environmentally Sensitive Areas

Areas that are critical for sludge disposal by landfilling exhibit environmental hazards and/or impose other limitations. Critical areas for sludge landfilling will generally include all those areas critical for municipal refuse landfills. In addition, because of the potential for sludge landfills to generate quantities of leachate well in excess of municipal refuse landfills, areas considered non-sensitive for refuse landfills may become sensitive for sludge landfills. Those areas for which the potential for contamination is intensified by the sensitivity of certain natural processes are characterized by:

- Steep slopes;
- Porous or unstable bedrock;
- A high water table;
- Critical habitats of endangered or threatened animals; and
- Vegetation which could be altered to the degree that it no longer supports viable populations of imperiled species.

Some critical areas for the burial of WWTP sludges are listed in Table 30.

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TABLE 30. SOME CRITICAL AREAS FOR LANDFILLING OF WWTP RESIDUALS (152)

- National Parks
- National Seashores
- National Lakeshores
- National Historic Parks
- National Memorial Parks
- National Recreation Areas
- National Battlefield Sites
- National Monuments
- National Wildlife Refuges
- National Forests
- State Parks
- State Wildlife Areas
- State Forests
- State Recreational Areas
- Designated or Potential Natural Areas
- Floodplains
- Inland and Coastal Wetlands
- Wet Soils
- Karst Topography
- Land with Slopes Greater than 8%
- Permafrost areas
- Critical Areas for Imperiled Species

A composite map of the areas where the storage or burial of sludge is severely limited is presented in Figure 31. These critical areas, shown in the darkened regions, represent all areas indicated in Table 30. This figure suggests that major operational and/or environmental difficulties will be experienced in the Appalachian Region, along the Atlantic and Gulf Coast Plain, in the Mississippi River embayment, in the central and northern Rocky Mountains, and in the Cascades-Sierra-Coastal Ranges section along the Pacific Coast (152).

Schmidt et al. (152) estimated the portions of each state which can be regarded as critical areas for the disposal of sludge on land. Based on their findings, the total quantified critical areas in the conterminous states is 547,799 square miles. This is approximately 18% of the total land surface of the conterminous states. Unquantified critical areas were suggested to account for up to 21% of the remaining land.

Other Considerations

Various landfilling design alternatives require excavated soils for ultimate sludge placement, dikes, or cover material. Clearing of topsoil and surface vegetation can enhance the erosion processes; wind and rainfall can remove underlying soils altering surface topography. Also, the leaching of contaminants from sludge landfill sites may accumulate in underlying

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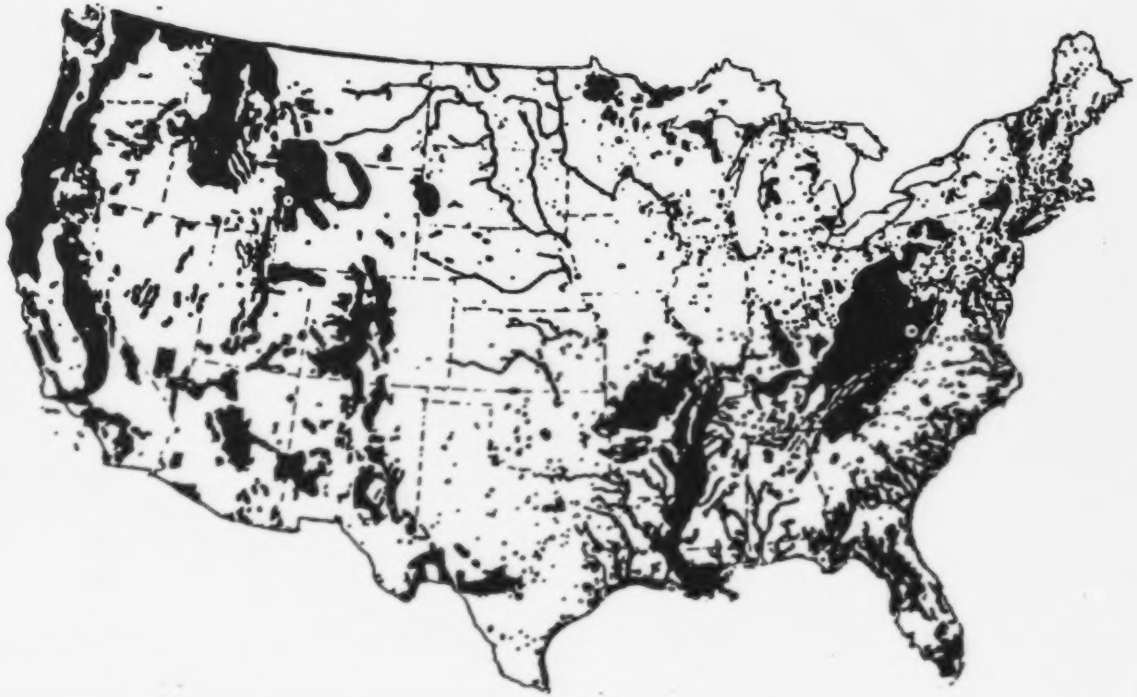

Figure 31. Darkened areas not suitable for the landfilling at WWTP sludge (from Schmidt et al (63))

or adjacent soils, making the soils unfit for natural flora, agricultural use, or other future uses.

In summary, sludge landfilling practices can be severely limited or restricted by critical wildlife habitats and unfavorable geohydrologic conditions. Site selection for sludge landfills should involve thorough investigation of the wildlife and eventual land use impacts.

SUMMARY

Sludge landfills can represent a significant threat to receiving waters, air, and land quality if improperly managed. Evidence suggests, however, that codisposal landfilling options can help mitigate potential impacts. For instance, codisposal practices were found to produce leachates of less strength than municipal refuse landfills. Though the high moisture content of sludge can lead to the production of vast amounts of leachates when subject to landfill surcharge loads, refuse can delay or prevent a codisposal landfill from reaching field capacity. There is, however, potential for increased odor and aerosol risks at codisposal sites in comparison to municipal refuse landfills. Codisposal and sludge-only landfills may also be limited by the environmental sensitivity of potential disposal sites. Because of the important advantage of codisposal operations in limiting leachate production from sludge, codisposal landfills are recommended over sludge-only landfills when landfilling is an acceptable sludge disposal alternative.

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SECTION 6

POTENTIAL PUBLIC HEALTH IMPACTS

The risk of transmitting disease is a major concern for any sludge disposal alternative. With regard to sludge landfilling, many reports have concluded that the hazard is substantial. For example, in a study of the potential health hazards associated with solid waste sewage sludge composting, Gaby (153) concluded that there is a significant public health hazard resulting from the handling and disposal of raw refuse and raw sewage. In an investigation of sludge burial by SCS Engineers (92), microbial contamination of ground waters based on fecal coliform and fecal streptococcus results was particularly pronounced. However, the reporting of disease by site operators, site users, or the communities surrounding sludge landfills is generally absent, and it is apparent that sufficient information is not yet available on the epidemiological significance of sludge landfilling.

The following discussion of the health risks associated with sludge landfilling is divided into the following groups of sludge contaminants (154):

- General water quality contaminants;
- Metal contaminants;
- Biocidal contaminants;
- Synthetic organic contaminants; and
- Biological contaminants.

General water quality contaminants are those which are traditionally associated with polluted waters. Table 31 lists the general water quality contaminants indicated in the sludge and refuse landfill leachate data from Appendix A. Most of the contaminants listed in Table 31 do not pose a direct threat to public health, but may be related to other public health impairing contaminants. For example, the presence of TOC in water may indicate the presence of refractory organic compounds. The nitrogenous compounds (ammonia, nitrates, and nitrites) may, however, pose direct threats to public health.

TABLE 31. MAJOR POTENTIAL CONTAMINANTS IN WWTP SLUDGE AND REFUSE

General Water Quality Contaminants

1. Chemical Oxygen Demand (COD)
2. Biochemical Oxygen Demand (BOD)
3. Total Organic Carbon (TOC)
4. Total Dissolved Solids (TDS)
5. Phosphates
6. Ammonia
7. Nitrates and Nitrites
8. Chlorides
9. Sulfates

Metal Contaminants

1. Iron
2. Zinc
3. Copper
4. Cadmium
5. Lead
6. Nickel
7. Manganese
8. Chromium
9. Mercury
10. Silver

Biocidal Contaminants (154)

1. DDT
2. DDD
3. DDE
4. Aldrin
5. Dieldrin
6. Endrin
7. Chlorinated hydrocarbons
8. Arsenated hydrocarbons
9. Organonitrogen pesticides
10. Organophosphorous pesticide
11. Herbicides
12. Soil sterilants

Table 31 also lists the metal contaminants listed in leachate data from Appendix A. Many of the metal contaminants are required in trace quantities in the human body for normal metabolic functions; however, higher concentrations may be toxic. Lead, mercury, and cadmium are of particular concern because they can be retained in the body for relatively long periods of time, thus functioning as cumulative poisons (155). Iron and manganese are mainly water quality nuisances rather than threats to public health (156).

The biocidal contaminants, also listed in Table 31, are compounds used to prevent, destroy, repel, or otherwise control objectionable insects, rodents, plants, weeds, or other undesirable forms of life. The general classification of biocides presented in Table 31 was taken from SCS Engineers (154). Many of the classes of biocides listed have been detected in sludge, as noted in Section 3.

Note that DDT, DDD, DDE, aldrin, dieldrin, and endrin are chlorinated hydrocarbons; they are separated from the chlorinated hydrocarbon classification because the literature often deals with those specific pesticides as individual entities. Much of the concern about biocidal contaminants, as well as other synthetic organic compounds and some metals, is related to the ability of aquatic plants and animals to store and concentrate these materials in their tissues, thus representing a potential hazard to humans using the animals for food. Some biocidal contaminants, particularly chlorinated hydrocarbon compounds, are highly resistant to biological degradation. Some of the biocidal contaminants are known to effect the central nervous system and others are suspected or known to be carcinogenic, teratogenic, or mutagenic.

The synthetic/organic contaminants (other than biocides) include the myriad of synthetically produced organic compounds that have found their way into refuse and wastewater systems. Some of the synthetic organic compounds in sludge have been identified in Section 3, the most notable of which is polychlorinated biphenyl (PCB). The human health impairing potential of many synthetic organic compounds is unknown, though some (e.g., PCB) are known health hazards with properties similar to biocidal contaminants.

Biological contaminants in sludge which can cause disease (or pathogens) have been tabulated in Section 3, along with the various diseases they may cause. High numbers of total coliform, fecal coliform, and fecal streptococci (approximately 10^8, 10^7, and 10^6 organisms per gram dry weight) have been observed in municipal refuse (153), indicating that refuse can be a potential source of microbial infections and a potential health hazard.

The potential for transmission of these contaminants from landfilling operations to man and the production of a disease response is governed by the following factors:

1. The initial concentration of contaminants in the wastes;
2. The nature of the contaminants in wastes (157);
3. Transformations of the contaminants within the fill or in transit (157);
4. Modes of transmission, e.g., by air, water, vector, or direct contact (157); and
5. The susceptibility and immunity of the host (157).

Item 1, the concentration of contaminants in sludge, have been discussed in Section 3. Items 3 and 5, contaminant transformations in the fill or in transit and host susceptibility, are mentioned where applicable in the following text. In discussing the potential public health impacts of sludge landfilling, efforts will focus on items 2 and 4 above, with major emphasis on the following:

- The identification of the pathways through which contaminants associated with sludge can intersect with man; and

- Public health considerations, including an epidemiological and pathological evaluation of sludge contaminants, including a description of the acute and chronic effects of the contaminants within the human body.

CONTAMINANT PATHWAYS

The transport and deposition of sludge to landfills can result in the direct transmission of potential health impairing contaminants to humans via aerosols, vector transport, direct sludge contact, groundwater or surface water runoff. Indirect pathways of contaminant transmission include groundwater, surface runoff, and surface water contamination of food crops, animal food, finfish or shellfish, and water recreation. These multiple routes of contaminant transmission are illustrated in Figure 32.

Because it would be difficult to implicate a sludge-only or codisposal landfill as the source of public health impairment for the various indirect pathways of contaminant transmission, particularly for recreational waters and aquatic life, the indirect pathways portrayed in Figure 32 will not be further discussed. Because of potential uptake of sludge contaminants by crops, agricultural usage of a closed landfill site should be avoided. The greatest indirect threat of contaminant transmission through sludge landfilling is in the use of contaminated groundwater or surface water for irrigation purposes. An extensive review of contaminant transmission via agricultural crops grown in sludge amended soil is provided by SCS Engineers (154).

Aerosols

The generation and transport of aerosol particles by wastewater processing systems including activated sludge, trickling filters, and spray irrigation has been the subject of considerable research which has been reviewed by Carnow *et al.* (158) and Fiscus *et al.* (159), among others. Literature dealing specifically with the generation and transport of aerosols from wastewater sludge processing, including landfilling and land application operations, is lacking. Therefore, the discussion of potential contaminant transmission by sludge aerosols will be based on analogous evidence provided by wastewater effluent processing systems.

Persons exposed directly to aerosols might become infected either because inhalation led immediately to a respiratory

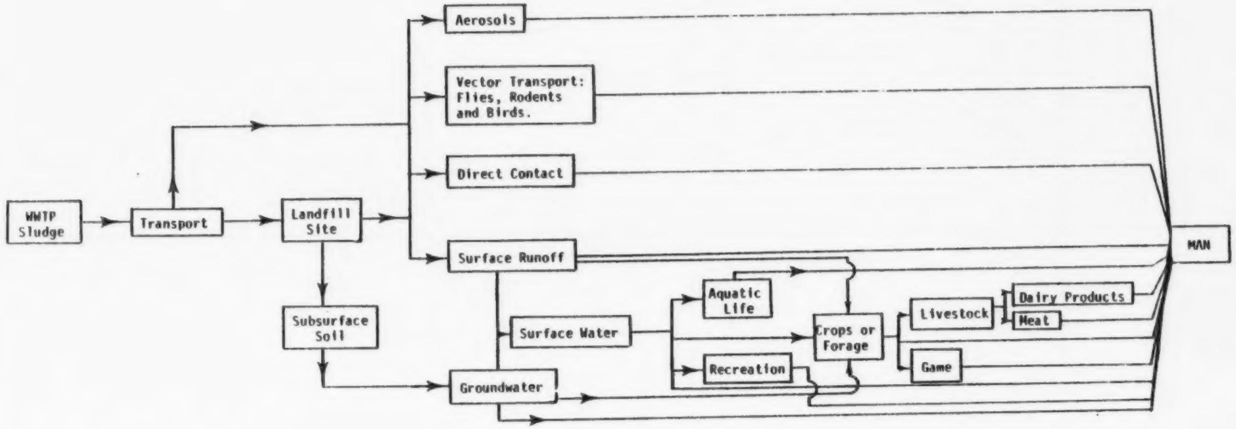
WWTP Sludge
Transport
Landfill Site
Subsurface Soil
Aerosols
Vector Transport: Flies, Rodents and Birds.
Direct Contact
Surface Runoff
Surface Water
Groundwater
Aquatic Life
Recreation
Crops or Forage
Livestock
Game
Dairy Products
Meat
MAN

Figure 32. Multiple routes of contaminant transmission from sludge landfills.

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infection or because swallowed respiratory mucus laden with trapped pathogens led to a digestive tract infection. Aerosols might also settle on food or water and lead to a digestive tract infection. The potential for infection and disease created by airborne wastewater aerosols has been the subject of considerable research in recent years. Evidence presented by Cliver (160) and Clark et al.(161) suggest that certain bacteria (e.g., Salmonella typhimurium and Klebsiella) and virus (e.g., coxsackievirus) may pose a direct health risk via inhalation. Thus, is appears that sludge aerosols must be considered a health threat by both ingestion and inhalation.

General Water Quality Contaminants--

In a comprehensive review of the health effects associated with wastewater treatment and disposal systems (154), SCS Engineers failed to locate any references concerning the transport of general contaminants (e.g., BOD, nitrates, etc.) via aerosolization. A review of more recent literature also fails to report aerosol transport of general water quality contaminants. In view of the chemical and physical nature of the general water quality contaminants, there seems little potential for atmospheric transport of these sludge constituents, and thus minimal potential health risk is involved.

Metal Contaminants--

Little work has been performed on the potential for aerosolization of this class of contaminants from wastewater processing systems. Northrop et al. (162) conducted air monitoring programs to characterize the type and extent of exposure of populations living near an activated sludge plant. Using fabric filters, the researchers sampled the air at regular intervals for 8 months for As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Se, Su, and V. Results indicated that the activated sludge treatment plant was not a source of high concentrations of these constituents, and in fact, the measured constituents were probably not associated with the plant. In another study, Cd, Hg, and Pb levels in the blood, feces, hair, and urine were examined in persons living in proximity to Chicago's John Egan wastewater treatment plant (163). Preexposure levels were compared to those found after the plant was fully operational. No statistically significant increases in metal content were seen in any of the fluids or tissues analyzed.

Though serving as a limited basis for drawing conclusions, the results of these studies indicate that there is little potential for aerosol transport of trace metal contaminants. The chemistry and physics of metal contaminants in sludge suggests that there is little chance for aerosol transmission of hazardous concentrations of metal contaminants from sludge-only and codisposal landfills.

Biocidal Contaminants--

Information on the transport of biocidal contaminants from wastewater processing facilities via aerosols or vapors is limited. Kominsky (164) describes an episode of acute exposure of sewage workers to vapors of hexachlorocyclopentadiene (HEX), an intermediate compound in the manufacture of pesticides. Workers experienced headaches and mucous membrane, and respiratory tract irritation. In another study (161), air samples taken at a wastewater treatment plant in Tennessee revealed substantial quantities of the chlorinated hydrocarbons hexachlorocyclopentadiene and hexachloronorbornadiene (HEX-BCH). The highest concentration of these substances in ambient air at several locations in the treatment plant was 280 $\mu g/m^3$ for HEX-BCH. Though no occupational standard for exposure to HEX-BCH have been established, the measured concentration is roughly double the threshold limit value of HEX (165). The same researchers also found that concentrations of trichloroethane, trichloroethylene, tetrachloroethylene, and chloroform on the downwind edge of a spray irrigation operation were well below the 8 hour occupational standards (161).

Each of these studies appears to be a rather isolated incident - incidents rarely encountered for most wastewater operations - in which pesticide and pesticide intermediates were in abnormally high influent concentrations. In such incidents, however, sludges may be the ultimate receptacle for such materials, since biocides have characteristically low solubilities. Vapors from such materials may continue to be a problem at landfill sites, though chances for aerosolization are much lower at landfills than at treatment plants where aeration of wastewaters can cause increased aerial dispersion. Nevertheless, the potential for health effects from biocides in aerosols from landfill operations seems possible. Research is needed to confirm such speculation.

Synthetic Organic Contaminants--

None of the literature reviewed considered the transport of synthetic organic material from wastewater processing activities via the aerosol route. Organic materials are generally insoluble or have limited solubility and tend to float in water surfaces. Their concentration at the air/water interface may increase the chances of aerosolization.

SCS Engineers (154) suggest that the primary significance of the concentration of organic materials in liquid surfaces and aerosols lies in the effect that these materials may have on the viability of biological aerosols. Supporting this suggestion is a study by Webb (166), which showed enhanced survival of several species of bacteria when amino acids, long chain protein degradates, some sugars, and polyhydrocylohexanes were added to atomizing fluids.

Biological Contaminants--

Circumstantial and analogous evidence exists to support the implication that viable aerosols could be a threat to the health of humans working or living in the exposed area near sludge landfills (167-170). However, there has not as yet been any definitive studies to substantiate this implication. The agents emitted from sewage sludges may be members of genera and species known to be pathogenic for man but whether these organisms survive in the aerosol environment, whether they retain their pathogenic characteristics in that environment, and whether they survive in quantities sufficient to be infectious and pathogenic for man are the critical but as of yet undetermined parameters.

Aerosols emitted from sewage and wastewaters have long been recognized as a potential health hazard. In the early 1900's it was first recognized that the aerosol created by flowing wastewater may be of public health concern. Studies by Harrocks (171) and Winslow *et al*. (172) demonstrated that sewage organisms could be recovered in aerosols some distance away from their respective sources. In the years that followed, numerous investigations were conducted in which sewage disseminated organisms were identified as far as 1600 km (approx. 1 mile) downwind from sanitary waste systems, which include wastewater treatment facilities and spray irrigation activity. These studies have been recently summarized by Carnow *et al*. (158). Whereas aerosol organisms have been identified near sewage treatment and disposal activities, no studies were identified which dealt directly with aerosols generated by sewage sludge discharge to landfills.

It is not yet clear from the literature what the complete spectrum of organisms is in aerosols originating from sewage. Research investigations are hampered by the multitude of meteorological, environmental, sampling, and cultural variables involved in the survival and recovery of a large variety of organisms. Organisms have been recovered at variable distances away from sewage treatment sites (Table 32) and on other occasions they have not been recovered (174). In summarizing the literature, the potential groups of bacterial organisms that have been reported to be recovered from wastewater aerosols include *Klebsiella* (161,173,175), *Pseudomonas* (173,176), *Clostridium* (173), *Aerobacter* (173,176), *Proteus* (175,177), hemolytic *Streptococci* (175), *Staphylococcus* (176), *Salmonella* (171), and *Mycobacteria* (173), not to mention other bacteria that are considered non-pathogenic except in opportunistic situations(158). Viruses identified in aerosols have included enterovirus and coliphages(178), though viruses have been less well-studied mainly due to technical and monetary limitations. Several studies (171,180) have demonstrated that workers at sludge compost sites and heat treatment areas are exposed to markedly elevated concentrations of airborne fungi spores of

TABLE 32. AN EXAMPLE OF GEOMETRIC MEANS AND RATIOS OF WASTEWATER AND AEROSOL CONCENTRATIONS OF MICROBIOLOGICAL PARAMETERS FROM A WASTEWATER SPRAY IRRIGATION SITE (FROM JOHNSON, ET AL. (173).

	Geometric Mean Wastewater Conc. (no./ml)	Geometric Mean Aerosol Concentrations (no./m^3 of Air)			Aerosol/Wastewater Ratio of Geometric Mean Concentrations	
		Upwind	Downwind		Downwind	
FIRST RUNS			5-20m	100-200m	5-20m	100-200m
Standard Plate count	699,000	805	2,570	880	0.0037	0.0013
Total coliform	7,500	< 0.5	5.7	1.2	0.0008	0.0002
Fecal coliform	800	< 0.3	1.0	0.3	0.0013	0.0004
Coliphage	220	< 0.1	0.34	0.18	0.0012	0.0006
Fecal streptococci	67	< 0.6	1.4	1.9	0.021	0.028
Pseudomonas	1,050	< 15	72	43	0.068	0.011
Klebsiella	390	< 5	< 5	< 5	<0.01	<0.01
Clostridium perfringens	54	< 0.9	1.5	1.1	0.027	0.020
		Upwind	Downwind		Downwind	
SECOND RUNS			50m	100m	50m	100m
Standard plate count	150,000	300	450	330	0.0028	0.0021
Total coliform	4,900	< 0.2	2.52	0.59	0.0005	0.0001
Coliphage	290	< 0.1	0.51	0.23	0.0017	0.0008
Fecal streptococci	34	0.15	0.34	0.29	0.0100	0.0085
Mycobacteria	46	0.30	0.80	0.82	0.0176	0.0178
Enterovirus	0.12		0.014		0.11	

Aspergillus fumigatus, and incidents of pulmonary abnormalities, ear infection and inflammation in workers are reported (169,180, 181). Fungi are ubiguitous in the environment and commonly found in sludge compost (182). Sewage sludge subjected to prolonged storage at a landfill site prior to burial or the exposure of buried sludge may provide conditions favorable to the growth of fungal colonies and release of spores. Sludge which is properly buried, however, is not a potential source of airborne fungal spores.

In general, three factors were repeatedly shown to be involved in maintaining the viability of organisms in aerosols: relative humidity, solar light exposure, and wind speed (183,184). High humidity favors most bacteria and some viral survival (185). Light (the ultraviolet light portion) is damaging to the genetic competence of bacteria and viruses (186). Light also has a desiccation effect (186). Wind speed was considered by Hickey and Reist (183) to reduce the transport time of viable organisms and thereby increase the dissemination of infectious material. However, wind speed can also effect desiccation of organisms and may thus offset their increased dissemination.

In review, considerable question remains as to the level of risk to be associated with microbiological aerosols from sludge and wastewater processing operations in the United States. Although bacteria and viruses are associated with wastewater solids and their initial concentration in sludge is generally higher than wastewater, the aerosol threat posed by sewage sludge discharge is likely to be less significant than wastewater processing since:

1. A soil cover is daily applied in sludge landfilling operations to minimize the potential for pathogenic aerosolization after covering but the act of covering itself would increase aerosolization of sludge

2. The sludge cake is normally dewatered prior to landfilling, creating a physical structure which is less amenable to the formation of aerosol droplets than spray irrigation or wastewater treatment processes. The dewatered sludge also represents an environment which to most pathogenic bacteria is less amenable to survival (but not viruses).

3. The sludge cake is normally stabilized prior to landfilling and the product is thus less pathogenic than raw wastewaters. Most of the stabilization processes discussed in Section 3 can inactivate or destroy substantial number of sludge pathogens.

4. Sludge discharge to the landfills normally involves

no "spraying' from tank trucks which enhances aerosolization.

Vector Transport

The mechanical transmission of sludge contaminants to humans by vectors is a viable yet rarely addressed pathway. Vectors have long been recognized for their ability to transmit pathogenic organisms, notable examples being implication in outbreaks of malaria and the plague. Vector transmission of non-viable contaminants cannot be considered a major pathway, although human ingestion of vectors which have accumulated non-viable contaminants is a feasible route. The chief source of concern for vector transport is direct human contact with potential disease carriers.

The major vectors associated with sludge and refuse at landfill sites are rodents, birds, and insects. Rodents can include a broad assortment of creatures including rats, ground squirrels, gophers, etc. Disease may be transmitted to humans by the bite of infected rodents. Birds, which may also forage in sludge and refuse, can transmit disease through contact with agricultural and household fruits or vegetables, or through contact with drinking water resources. Rodents and birds can act as reservoirs for infection (187). Flying insects, such as flies and mosquitoes, are a particularly important group of vectors from a human health standpoint, inasmuch as their numbers can be large and they can have easy access to man, surface waters, and crops.

Mosquitoes may breed in stagnant pools on-site, and contaminated mosquitoes are capable of transmitting disease primarily through bites, though disease transmission through direct contact cannot be ruled out (personal communication, Dr. Sleeper, Long Beach State University, Long Beach, California). The implication that mosquitoes are a health hazard associated with sludge landfills would be difficult to support since other water bodies and irrigation water could also serve as breeding grounds. However, this does not remove the possibility that sludge and refuse landfills can serve as a source of contamination for mosquitoes.

With reference to flies, Stone (37) reports that houseflys and blowflies were the most numerous insects at a sludge landfill demonstration in Oceanside, California. Human contact with flies foraging in sludge offer opportunities for the transport of pathogens. Although various species of flies have been found carrying the germs of poliomyelitis, cholera, leprosy, or tuberculosis (187), there is no evidence that they are involved in transmission to any extent because of epidemiological limitations. Even correlations of fly abundance and disease incidence is not proof, since both could depend, quite separately, on climate (188). The only entirely convincing evidence of the importance of flies as vectors is a decline of disease following fly reduction, which is not seen in untreated "control" areas. Only two types of disease are definitely implicated in this way-bowel diseases and eye infections (187).

Flies may transport pathogens via the fly's contaminated feet or by so-called "vomit drops" of partially digested food (187). Busvine (187) states that perhaps the commonest method of transmission is through the fly's feces. The passage through the gut is quite rapid and many organisms can pass out unharmed (187). Defecation in well-fed flies can occur every five minutes (187).

In summary, the potentially important disease carriers at landfill sites include rodents, birds, and insects, particularly flies. Unlike rodents contact, the tracing of human infection and disease incidents to birds and flies can be extremely difficult. Direct evidence that birds and flies are involved in pathogen transmission is lacking. Nevertheless, the potential for vector transmission cannot be dimissed.

Direct Contact

The potential for transmission of contaminants from sludge to man through direct sludge contact is (in most cases) limited to site workers and operators who risk direct and indirect contact with sludge daily. Site trespassers or children are likely to venture onto a landfill site only after operating hours, in which case the sludge is likely to be covered and thus not a risk for direct contact contaminant transmission. Contact with sludge or sludge-spattered vehicles or equipment can be hazardous provided: (1) hands or arms contacting the sludge have open sores or cuts (broken skin) which are amenable to infection, and (2) sludge contaminated clothing or body surfaces contact the mouth area or any other mucus membrane or contaminate food and the contaminants are ingested.

Sludge contaminants capable of causing disease in this manner are probably limited to biological contaminants, although it may be possible for a skin irritation to develop from sludge biocidal or organic contaminants (165). Incidence of sludge workers contacting infection or disease which is attributable to sludge contact is undocumented.

With proper site safety measures and reasonable habits of personal hygiene, the chances of contaminant transmission through direct sludge contact seems minimal. That portion of the population with potential for sludge contact through landfilling is relatively small.

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Ground Water

Disposal of sludge to land by land treatment or landfilling has generated much concern over the potential for contaminant transmission through ground water and agricultural crops. This concern appears justified since these are the most direct pathways leading to humans. The research emphasis has also been largely associated with the elemental, biological, and general contaminants which provide plant nutrients, such as the nitrogen and phosphorus species. Until recently, very little research had been conducted on the transmission of synthetic/organic and biocidal contaminants to ground water.

As indicated in Section 5, sludge landfilling can have adverse effects on underlying ground water and surface waters from sludge leachates and surface runoff. Provided that effective surface runoff control measures are implemented at the landfill site, the major potential hazard of sludge landfills is contamination of ground-water supplies (92). Recent increases in land treatment and disposal of sludges have led to new interest in the ability of soil systems to remove or inactivate leachate contaminants. Mechanisms through which soils can accomplish this activity include filtration, ion exchange, chemical complexation, adsorption, and biological processes. The downward movement of water and dissolved constituents also depends on precipitation and depth of the water table. This section evaluates the potential for contaminant transmission via the ground water pathway.

General Water Quality Contaminants--

The emphasis of research concerning the migration of general contaminants in sludge leachates through soils and ground water deals with nitrogen and phosphorous species. Walker et al. (82) states that the most probable environmental risk from entrenching dewatered sludge is the possible pollution of ground water with nitrogen. Nitrogen is present in sludge as organic nitrogen, ammonia, and nitrate. Although some ammonia may be lost by vaporization, most is converted aerobically to soluble nitrate, which will move with soil water (189). Nitrates in concentrations over 20 to 40 mg/l are considered dangerous to human infants (190) for reasons described in the following section, Public Health Considerations. Phosphorus (P) is important because of its "eutrophication potential" (potential to accelerate the nutrient enrichment of waters).

In acid soils, phosphorus is adsorbed or precipitated by crystalline and/or amorphous iron and aluminum oxides. In neutral or calcareous soils, phosphates react with calcium to form, depending on ionic composition, a number of slightly soluble or insoluble calcium phosphates. A number of long-term studies involving land treatment with sewage sludges have demonstrated that phosphorus movement through soils is usually restricted (191,192). However, in cases where liquid sludges

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are applied at high rates, phosphorus movements to considerable depths (i.e., 3-10 m) in soil profiles has been observed (113, 193).

A number of studies have demonstrated substantial concentrations of nitrate (NO_3-N) at depths in soil well below sludge trenches and root zones (i.e., 2-12 m). Walker et al. (124) observed increased nitrate movement through the soil in two years following sludge entrenchment. Lund, Page, and Nelson (113) reported concentrations of NO_3-N greater than 400 mg/l at a depth of 23 m below a sludge lagoon. The lagoon had been used to dewater sludge for about 20 years. On an off-site control at the same depth (23m), the concentration of NO_3-N was 30 mg/l. King and Morris (194) and Kardos and Sopper (195) observed substantial increases in NO_3-N in soils at a depth of 2.3 m beneath fields receiving either sludge or effluent applications.

Aside from nitrate and phosphorus, chloride appears to represent the only other general contaminant which might threaten ground-water quality through soil movements. Lofy et al. (196) reported chloride values in ground water 91 m (300 ft) downstream from a sludge landfill site ranging from 5 to 3,000 ppm. Chloride is not of public health significance.

Metal Contaminants--

Considerable research has been directed toward the possible hazards to health from accumulation of certain elements in water supplies and food. For example, the cumulative toxicity of cadmium to the human kidney and liver is well-documented (197,198,199). The movement or attenuation of trace metals in soil are governed by the chemical properties of the soils and the sludge leaching solution itself. Generally, those trace elements which occur in solution in a molecular or anionic form tend to migrate to greater depths in the soil profile than do trace elements which occur as cations in solution (200). If organic ligands, such as humic acid type materials, are present in the aqueous phase of the sludge, stable complexes which readily migrate through soils, may be formed.

Lofy et al. (196) collected off-site shallow ground-water samples near eight subsurface sludge disposal sites and analyzed the waters for total Cd, Cu, Fe, Hg, and Pb. Of these elements, Cd, Fe, Hg, and Pb were found to exceed USPHS Drinking Water Standards on several occasions. Lead and iron were found to exceed the drinking water standards most often although the reasons for this were not addressed. The study concluded that the contaminants were entering the ground water in the vicinity of the case study landfills. On the other hand, Walker et al. (124) found that metals did not move out of entrenched sludges into soils as long as sludge pHs remained near neutral. In entrenched, unlimed sludge, in which the pH became acidic, slight metal movement was observed. Lund, Page, and Nelson (113) presented data which showed movement of Cd, Cu, Ni, and Zn to a depth of at least three meters in a soil beneath a 20 year old sewage lagoon. Page (200) showed evidence that of eleven metals analyzed, only boron moved in substantial amounts to depths lower than 20 cm in the soil profile. Boron is known to be quite mobile in soils.

Generally, maintaining sludge and soil pH near neutral or slightly alkaline aids in immobilizing heavy metals (82). Lime treatment of sludges can help to maintain a higher sludge pH once landfilled. However, as sludge biological activity proceeds, the sludge pH will drop (124). Trace metal contamination of ground waters from sludge and refuse landfills is well-documented, and must be a major human health concern for sludge-only and codisposal landfilling activity.

Biocidal Contaminants--

The chemical properties of organic biocides and their reactivity with soil materials determine to a great extent the ultimate fate and behavior of these compounds in soil and in the environment (201). The important chemical properties of biocides include:

- Ionizability (ionic charge);
- Water solubility;
- Volatility (vapor pressure); and
- Molecular structural effects (polarity, functional groups, steric effects).

In general, only highly water soluble, nonionizable pollutants and pollutants which ionize to negatively charged forms tend to be relatively mobile in soils (202). On the other hand, of the seemingly innumerable biocides, most tend to be of low water solubility and nonpolar, which would restrict their mobility. Van Bladel and Moreale (203) studied herbicide adsorption by clay minerals. The authors found that adsorption appears to be one of the most important factors in controlling pesticide removal from soil layers by leaching as well as chemical and microbial breakdown.

In view of the relatively low concentration of biocides commonly observed in sludge and their usually restricted mobility in soils, the risk of biocide transmission from sludge burial sites through ground water appears small. Additional research is required to further define the movement of biocides in soils and ground water to adequately assess the risk.

Synthetic Organic Contaminants--

Although considerable effort has been expended to document the various aspects of environmental contamination by PCBs and other synthetic orgnaics, the transport mechanisms are still poorly understood, particularly in soil systems (204). The present information suggests that PCBs are strongly adsorbed by soil materials (205, 206, 207) and are not readily leached by percolating water (208). Scharpensell et al. (209) also found that PCBs were not readily leached from soil and that the PCBs recovered from soil were associated with the soil's organic matter. Research by Griffin et al. (204) concluded that Aroclors 1242, 1254, and capacitor fluid remained immobile in soils when leached with water of sanitary landfill leachate. They also stated that the mobility of PCB and DiCamba (a pesticide) was related to their solubility in leaching solvent, and to soil TOC content (i.e., greater TOC led to greater PCB mobility).

To date, research dealing with sludge disposal in terms of synthetic organic contaminant migration and potential ground water degradation is lacking. Available literature seems to indicate that PCB movement in soil is restricted. Further research is needed to identify potential organic contaminants in WWTP sludge and their mobility in soils and ground-water systems.

Biological Contaminants--

The potential transmission of pathogens through soils and ground water is a special public health interest in the deposition of sewage sludge to landfills. Considerable research has been directed toward ground-water contamination by pathogens from wastewater and sludge disposal to land, and from sanitary landfilling activities. In general, the primary factors governing the degree of hazard to ground and surface waters presented by pathogenic organisms in sludge and refuse landfills are (33);

- The initial concentration and nature of pathogen in the waste;
- The extent of survival of pathogens within the fill; and
- The possibility of pathogens leaching from the fill into the ground water.

Section 3 has established that municipal sewage sludges may be heavily contaminated with pathogens. According to Parrokova (210), refuse is an excellent medium in which pathogenic microorganisms survive, as do intestinal parasites in certain life stages. Table 33 presents the relative concentrations of several groups of microorganisms in refuse, sewage sludge, and refuse/sludge mixtures, as reported by Gaby (153). Refuse shows high levels of pathogens as does sewage sludge and refuse/sludge mixtures.

TABLE 33. CONCENTRATION OF MICROORGANISMS IN REFUSE, SEWAGE SLUDGE, AND MIXTURES (153)

	Total Coliform[a]	Fecal Coliform[a]	Fecal Streptococci[a]	Salmonella Shigella[a]
Refuse	10^8	10^7-10^8	10^6	very negligible
Sewage sludge	10^8	10^8	10^4	-
Refuse sludge	10^8	10^7-10^8	10^6	-

[a] bacterial count per gram dry weight

Regarding the nature of sludge and refuse pathogens, Appendix C shows evidence of the infectivity and virulence of many pathogens identified in sludge and refuse. Given the initial content and nature of sludge and refuse pathogens, the extent of their survival in a landfill environment must be examined, as well as possible leaching or runoff of pathogens from the site.

Pathogen survival--Several studies have been conducted on pathogen survival in landfill environments. A study conducted by Gaby (153) on the end product of refuse-sewage sludge composting concluded that an anaerobic windrow, simulating anaerobic landfill conditions, does not generate sufficient heat to kill undesirable microorganisms. Since most of the pathogenic bacteria found in raw refuse are facultative anaerobes, these organisms would survive (153). Insertion studies indicated that the number and growth of coliform bacteria diminished continuously in composted refuse, but examination of compost at later dates indicated that coliforms reappear (153).

Conversely, Stone (39) found that the upper range of temperatures generally found in sanitary landfills, with or without sludge addition, is 45 to 65°C. The higher end of the landfill temperature range in combination with prolonged exposure times is sufficient to destroy most non-spore forming bacteria (157). He concluded that mechanical mixing, pressure developed by succeeding lifts, and possible thermal conditioning provided by decomposition heat can help to destroy or inactivate pathogens (39).

Other factors may also be of importance in the suitability of refuse, sludge, or refuse-sludge mixtures as a medium of growth for pathogens. Studies have shown that leachate percolating through municipal refuse landfill can be of sufficient strength (118,119) or pH (118,211) to kill or inactivate bacteria and viruses. Section 5 indicated that sludge-only and codisposal leachates can be of comparable strength to municipal refuse leachates. In spite of the potentially harsh landfill conditions, various studies have indicated that there is a significant pathogen (particularly bacteria) population associated with sludge landfill leachate (39,92). Viruses are probably also present because they are generally more resistant to conditions than bacteria. For pathogens washed from the sludge and refuse, removal by the soil constitutes the next barrier to migration to ground water.

Pathogen migration through soil and ground water--In a review of the literature, McGauhey and Krone (212) concluded that soils should provide an effective medium for removal of bacteria from infiltrating water and hypothesized that viruses also would be effectively removed. More recent work, however, has shown that soils can indeed effectively remove virus from water but that under certain conditions both viral and bacterial movement may be extensive. Lofy *et al*. (196) reported contamination of ground waters by fecal coliform and fecal streptococci up to 91.4 m (900 ft) downgradient from a sludge landfill site. Gerba *et al*. (273) noted coliform movements in a variety of soils for distances ranging from 0.9 to 456 m (3 to 1500 ft). Some bacteria can travel for miles through limestone areas (214). Merrell *et al*. (215) reported that viruses injected into percolating water were removed only after 61 m (200 ft) of horizontal and vertical travel. In a comprehensive review of the potential for parasitic disease transmission from land application of sewage plant effluents and sludge, Hays (75) cites no studies concerning the migration of parasites through soils or ground water. Likewise, fungus movement in soils is undocumented.

Evidence indicates that the movement of bacteria and viruses in soils is largely restricted as a result of adsorption and filtration (214,216,217,218). Thus the size of an organism and the type of soil affects the distance the organism travels in the soil. Heavy textured clay soils would be especially restrictive to movement. Parasites are comparatively large organisms, thus their movement would be inhibited in soil. Viruses, on the other hand, are so small that they should move through soil pore systems easily if they are not adsorbed by small particles. The mechanism of adsorption is of interest because both bacteria and viruses are negatively charged at most soil pHs (219). Since the soil is also negatively charged, repulsion instead of adsorption might be expected.

Pathogenic organisms may survive in soils for periods varying from a few hours to several months, depending on the type of

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organism, soil moisture, soil temperature, pH, and predation and antagonism from the resident microbial flora (212,220). A compilation of pathogen survival in soils data in the literature is shown in Table 34. From Table 34, it appears that parasitic ova and spore-forming bacteria are the most persistent pathogens in soils.

TABLE 34. SURVIVAL OF PATHOGENS IN SOILS (221)

Pathogen type	Name or species	Length of survival, days
Virus	Poliovirus	≤ 84
Virus	Poliovirus 1	≤ 170
Virus	Echo 7	≤ 170
Virus	Echo 9	≤ 170
Virus	Coxsackie B3	≤ 170
Bacteria	*Clostridium* sp	≤ 210
Bacteria	*Leptospira* sp	≤ 43
Bacteria	*Mycobacterium tuberculosis*	≥ 180
Bacteria	*Salmonella* sp	≤ 570
Bacteria	*Salmonella typhi*	≤ 120
Bacteria	*Shigella sp*	≤ 210
Bacteria	*Streptococcus faecalis*	≤ 210
Bacteria	Total Coliform	≤ 210
Parasite	*Entamoeba histolytica* cysts	≤ 8
Parasite	*Ascaris lubricoides* ova	≤ 2,550
Parasite	Hookworm larvae	≤ 42

In review, evidence suggests that pathogenic organisms, including various bacteria virus, parasites, and fungi, are capable of surviving in landfill environments. Decomposition heat and high strength leachates can inhibit bacterial and viral survival in both sludge and refuse landfills, but does not assure their inactivation or destruction. Once leaching through the landfill, various factors can influence the distance the pathogens can disperse, including organisms survival rates, the size of the oragnism, the type of soil, and the rate and direction of ground-water movement. Pathogenic organisms may survive in soil for periods varying from a few hours to several months, depending upon the type of organism, the soil moisture and pH, and predation by other organisms. They may travel for miles in ground water through solution cavities in limestone areas or may be immobilized near the surface of heavy textures soils. Aforementioned evidence suggests that the ground-water pathway should be of primary public health concern when landfilling municipal WWTP sludges.

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Surface Runoff and Surface Waters

Sludge and refuse contaminants in surface water runoff pose a potential public health threat because of possible direct contact and receiving water contamination. Receiving waters include potential sources of drinking water, irrigation water, or recreational water. The quality of runoff from land spreading of sludge has been the subject of considerable research. Landfilling or burial of sludge is expected to diminish the chances for contaminated runoff, provided steps are taken to cover the sludge and minimize on-site sludge storage. The following comments briefly describe the transformation and fate of public health and environmental impairing contaminants in surface waters.

General Water Quality Contaminants--

Most of the general contaminants (BOD, oil and grease, phosphates, etc.) are not of immediate health concern in surface waters, although they often degrade the quality of an aquatic habitat. The input of BOD to freshwater systems and the oxidation of such organic material by microorganisms may deplete the oxygen content of the receiving waters. An indirect consequence of the introduction of BOD and suspended solids to receiving waters is their association with some of the public health impairing contaminants.

In most surface waters, ammonia nitrogen is converted to other nitrogen forms mainly through biological nitrification. The normally long retention time in lakes allows nitrification to convert most of the ammonia nitrogen entering the lake into nitrate nitrogen, a potential human health threat as discussed later. Nitrate nitrogen is quite soluble in water and is not adsorbed to any significant extent on particulate matter. It is relatively nonreactive chemically under the conditions found in natural waters. Therefore, the major factors influencing the transformation of nitrate nitrogen is biological action, including incorporation into organic matter by both autotrophic and heterotrophic organisms, and reduction to either nitrites, also a health threat, or nitrogen gas under anaerobic conditions.

Phosphate is not a direct health-impairing contaminant. However, excessive amounts of phosphate in surface waters along with the nitrogen species may lead to eutrophication.

Metal Contaminants--

Trace metal contaminants are transported through freshwater systems in two forms: (1) in solution and (2) as physically or chemically adsorbed to suspended particles. As the contaminants travel through rivers and lakes, they may settle to the bottom and/or be adsorbed by sediment. Depending on environmental conditions, these metals may later be desorbed

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from particulate matter and reenter the water column.

Perhac (222) conducted research on the distribution of cadmium, cobalt, copper, iron, manganese, nickel, lead, and zinc in dissolved and particulate solids in two streams and concluded that:

1. The lowest concentrations of metal occur in the dissolved state. Coarse particulates are enriched an average of about two to 10 times relative to the dissolved solids. The colloids are enriched by over 10 times relative to the dissolved solids.

2. Despite the low concentration of metal in the dissolved solids nearly all of the heavy metal content in the streams is in solution. This is due to the large quantity of water relative to solid fractions. The colloids typically account for less than 1% of the total heavy metal content of water.

Biocidal Contaminants--

Surface water runoff is considered to be the single most important source of pesticides in freshwater. Once a pesticide enters a water body, it may be volatilized to the atmosphere, biologically degraded, remain in solution or suspension, or be deposited as sediment.

Among other studies, Eichelberger and Lichtenberg (223) performed an extensive study on the stability of common pesticides in raw river water (contaminated by domestic, industrial, and agricultural sources), and the chemical and biological degradation products of these compounds. Twelve organochlorine, nine organophosphorus, and seven carbamate pesticides at concentrations of 10 μg/l were laboratory analyzed for an eight week period. Five of the twelve organochlorine compounds underwent a change during the study period. All eight thiophosphate compounds evidenced some degree of chemical change. The carbamate compounds completely disappeared from the water within the eight week period. Table 35 presents the degradation rates indicated in the results of the study.

Synthetic Organic Contaminants--

There has been a great deal of activity lately in regard to identification of synthetic organic trace compounds in water supplies drawn from rivers and other water bodies receiving treated sewage. Although studies of the concentrations found in various water systems have been made, the potential health effects of these substances are yet to be determined. Like pesticides, synthetic organic contaminants (e.g., PCB) can be refractory in nature, remaining in a water system for years. Because of the low solubility of PCB's in water, the bulk of

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TABLE 35. PERSISTENCE OF PESTICIDE COMPOUNDS IN RIVER WATER (223)

Compound	Original compound found, percent				
	0-time	1 wk	2 wk	4 wk	8 wk
Organochlorine Compounds					
BHC	100	100	100	100	100
Heptachlor	100	25	0	0	0
Aldrin	100	100	80	40	20
Heptachlor epoxide	100	100	100	100	100
Telodrin	100	25	10	0	0
Endosulfan	100	30	5	0	0
Dieldrin	100	100	100	100	100
DDE	100	100	100	100	100
DDT	100	100	100	100	100
DDD	100	100	100	100	100
Chlordane (tech.)	100	90	85	85	85
Endrin	100	100	100	100	100
Organophosphorus Compounds					
Parathion	100	50	30	<5	0
Methyl parathion	80	25	10	0	0
Malathion	100	25	10	0	0
Ethion	100	90	75	50	50
Trithion	90	25	10	0	0
Fenthion	100	50	10	0	0
Dimethoate	100	100	85	75	50
Merphos	0	0	0	0	0
Merphos recov. as Def	100	50	30	10	<5
Azodrin	100	100	100	100	100
Carbamate Compounds					
Sevin	90	5	0	0	0
Zectran	100	15	0	0	0
Matacil	100	60	10	0	0
Mesurol	90	0	0	0	0
Baygon	100	50	30	10	5
Monuron	80	40	30	20	0
Fenuron	80	60	20	0	0

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PCB residues in streams is associated with suspended sediment, bottom material, and aquatic organisms (224).

Biological Contaminants--
As opposed to pathogens introduced into soils where mobility is more restricted, biological contaminants are readily carried and dispersed in water. Generally speaking, pathogenic survival time in water is less than that for soils (154), and the dilution rate is greater for water systems. However, the impact of pathogens in freshwater systems is far greater than in contaminated soils because of the possibility of more direct public contact.

The survival times of various microorganisms in freshwater are listed in Table 36. The data presented here (225) relate the average time for 99.9% reduction of the organism in water. An examination of the Table reveals that microorganisms may survive for long periods of time. Thus they travel great distances downstream before environmental factors cause mortality or inactivation.

Summary

From evidence presented in the preceding discussion, the ground-water pathway presents the greatest risk of contaminant transmission from sludge landfilling activities. Contaminants capable of passing through soil into ground water can be mechanically transported elsewhere for potential reception by man at some distance and at some other time. The pathways with the greatest chance of public contact are perhaps ground water and surface waters. Although measures can be implemented to minimize the potential for surface water contamination by runoff, this pathway, like ground water, merits special public health consideration. The risk of contaminant transmission via alternate direct pathways including aerosols, vector transport, and direct waste contact, appears minimal. The degree of exposure to these alternative pathways will govern the risk of contaminant transmission, the risk being greatest for workers at the site, less for visitors to the site, and less still for those who live near the site.

PUBLIC HEALTH CONSIDERATIONS

The transmission of sludge contaminants to man does not necessarily produce infection or disease. Though many contaminants, under the right circumstances, are capable of producing disease, the probability of infection or disease also depends on the immunity and susceptibility of the host (157). Healthy people have been known to inhale, ingest, or contact contaminants and still not contact disease because body cells and tissues possess efficient mechanisms of defense (226).

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TABLE 36. AVERAGE TIME IN DAYS FOR 99.9% REDUCTION OF ORIGINAL TITER OF INDICATED MICROORGANISMS IN FRESHWATERS (225)

	Little Miami River (Ohio)			Ohio River (Ohio)		
	Temperature					
Microorganism	28°C	20°C	4°C	28°C	20°C	4°C
Poliovirus I	17	20	27	11	13	19
Echo 7	12	16	26	5	7	15
Echo 12	5	12	33	3	5	19
Coxsackie A9	8	8	10	5	8	20
A. aerogenes	6	8	15	15	18	44
E. coli	6	7	10	5	5	11
S. fecalis	6	8	17	18	18	57

The following discussion summarizes the health effects to man of ingestion of potential health impairing contaminants found in sludge. Because it is outside the scope of this report to review in detail the types of diseases, infection, and dosages required to produce infection, the information is largely compiled in tabular form. Information on classical acute health effects of relatively toxic chemicals is available from physician's manuals, but knowledge of the chronic health effects associated with long-term exposure to low level concentrations of chemical substances is not well-documented.

General Water Quality Contaminants

Of the general water quality contaminants discussed, the human health effects of nitrate- and nitrite-nitrogen are of primary concern. Nitrogen in WWTP sludge usually takes one of the stable forms of ammonia, nitrate, or organic nitrogen rather than the more hazardous nitrite form. However, the potential health hazards of nitrate are significant as referenced by the National Institue of Environmental Health Sciences (217) and the Hazardous Waste Advisory Committee of the EPA (228). In high concentrations and under special circumstances, nitrite may cause illness and even death. When ingested, nitrates are generally toxic only by virtue of their potential for chemical conversion into nitrites.

The major clinical manifestation of acute nitrite toxicity is cyanosis (a bluish-purple discoloration of the skin and lips, which generally occurs within 1 or 2 hrs after ingestion) and if unrelieved by oxygen therapy, there may be nausea, vomiting, and profuse sweating--in severe cases, lethargy--progressing to unconsciousness. Death from asphyxia may result when large amounts of methemoglobin, the oxidized form of hemoglobin, are formed and oxygen transport is severely impeded (218).

Methemoglobin is normally present in blood, constituting about 1% of the total hemoglobin of a healthy adult and up to some 4% of the total hemoglobin of a healthy newborn infant. Levels about 6% have been observed in normal babies with respiratory illness or diarrhea. Cyanosis results when roughly 15% of the hemoglobin in blood is converted into methemoglobin. When methemoglobin constitutes 70% or more of the total hemoglobin, death may occur (227).

As indicated previously, nitrates are toxic to man because of their potential for reduction into nitrites. Such a conversion of nitrates into nitrites may occur outside the human body (in nitrate-containing food or water prior to ingestion) or inside the human body (by the action of intestinal bacteria or ingested nitrates).

The form of nitrate/nitrite conversion that occurs during digestion requires very special conditions, ones that are likely to be present only in infants (227). The foremost prerequisite is the presence of nitrate-reducing bacteria which are found only in the upper gastrointestinal tract. This circumstance may occasionally occur in infants, particularly those with gastrointestinal infections and a gastric pH too high to kill the bacterial

Several other factors explain why most cases of clinical nitrate-induced methemoglobinemia occur in infants: (1) the hemoglobin of a very young infant (so-called fetal hemoglobin) is oxidized twice as rapidly by nitrite to form methemoglobin as the hemoglobin of children and adults; and (2) the red blood cells of infants are not able to reduce methemoglobin into hemoglobin as well as that of adults (228).

The most common cause of methemoglobinemia is the ingestion of water containing high levels of nitrates. This has accounted for many more cases than all other causes combined (nearly 2,000 reported in the U.S. and Europe) (190).

Metal Contaminants

Accurate knowledge of the health effects of metals and their compounds is often difficult to assess. Many metals are essential to life at low concentrations but toxic at high concentrations. Because the varied chemical states of metals (the pure metal, inorganic metallic compounds or organic metallic compounds) react differently within the body, the situation is further complicated. Factors such as individual differences between subjects, incubation period, and sites of accumulation of the substances in the body are significant variables in their toxicity. In addition, most experimental data has been obtained from animals; this data may not be readily transferrable to humans.

Of the heavy metals, five elements (cadmium, lead, mercury as methyl mercury, nickel as nickel carbonyl, and beryllium) represent known hazards to human health, based on existing evidence. Lead, mercury, and cadmium are particularly insidious because they can be retained in the body for relatively long periods of time, thus functioning as cumulative poisons.

Table 37 provides a comprehensive summary of the presence of metals in the environment, their toxicity to humans, and their half life in the body. As can be seen from the Table, the most toxic of these metals are antimony, arsenic, cadmium, lead and mercuric salts.

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TABLE 37. METALS IN THE ENVIRONMENT AND THEIR TOXICITY TO AVERAGE ADULT MALE (155)

Metal	Average daily intake (mg dry wt.) food and water	air	Oral dose to produce toxicity (mg)	Fatal dose by ingestion (mg)	Normal total body content (mg)	Whole body half-life (days)
Antimony	0.1	0.0017	100	100-200	7.9	38
Arsenic	0.4-0.9	--[a]	5-50	120	15-20	280
Barium	0.74	0.03	200	1,000	22	65
Beryllium	0.012	4×10^{-5}	--	not known	0.3	180
Cadmium	0.16	0.0074	3	not known	50	200
Chromium	0.245	0.0011	200	5,000[b]	1.8	616
Copper	1.325	0.0114	50-250	10,000	72	80
Iron	15.0	0.084	--	5,000-10,000[c]	4,200	800
Lead	0.3	0.046	--	500	120	1,460
Manganese	4.4	0.028	not known	--	12	17
Mercury	0.025	--	--	20-1,000[d]	--	70[e]
Nickel	0.6	0.00236	--	--	10	667
Selenium	0.062	--	5	--	14.6	11
Silver	0.06-0.08	--	60	2,000[f]	1	5
Tin	7.3	6×10^{-4}	2000	--	17	35
Zinc	14.5	0.0168	--	10,000[g]	2,300	933

[a] not given
[b] copper sulfate
[c] two-yr old child
[d] mercuric salts
[e] methyl mercury
[f] silver nitrate
[g] zinc/sulfate

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Biocidal Contaminants

In the literature, significant information is documented concerning biocidal contaminants. Because of their persistence and non-degradational characteristics, many of the relatively less toxic chlorinated hydrocarbon pesticides such as DDT, aldrin, and dieldrin have been banned and are being replaced by highly toxic but less persistent organophosphorus pesticides.

In the chemical and medical literature, hundreds of acute poisonings resulting directly or indirectly from pesticides have been reported. Table 38 shows the toxicity of typical biocides.

Synthetic Organic Contaminants

In regards to the relationship between these compounds in water and human disease, there is very little evidence available. Cancer has been the disease of most concern as possibly resulting from long-term exposure to low concentrations of synthetic organic contaminants.

PCBs are the most noteworthy of the synthetic organic contaminants and are highly toxic to many aquatic and terrestrial organisms (300). The limited study to date indicates that uncontaminated PCBs have a very low toxicity to man. According to the Food and Drug Administration, the average PCB concentration in a normal American diet is only about 10% of the FDA's strict safety levels set in 1971 for food, food packaging materials, and animal feeds (155). However, it is not understood whether PCBs will have any chronic sublethal effects on man.

Biological Contaminants

Pathogenic microorganisms are a threat to public health to the degree that (160):

1. Susceptible people are actually exposed to them;

2. An infection results from the exposure; and

3. Disease results from the infection.

Infection can be defined as the establishment and propagation of an agent in a host. Cliver (160) notes "infection by an enteric agent can frequently be confirmed by showing that more of the agent is shed in the stool than what was originally fed to the host; infection can also be inferred if the host begins to produce antibodies against the agent that was administered. An infectious dose of an agent is the smallest quantity that produces infection."

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TABLE 38. BIOCIDES IN THE ENVIRONMENT AND THEIR ACUTE TOXICITY (155,229).

Biocide	LD_{50}^{*} (oral) mg/kg	48-hr TLm^{+} Values From Static Bioassay	Chronic Poisoning (to humans unless stated otherwise)	Acute Poisoning
DDT	Rat 285	Bass 2.1	Not substantiated. Having 648 mg/kg in their body remained well.	Severe vomiting within 30 min to 1 hr of 5 mg. Weakness and numbness of the extremeties. Apprehension and excitement are marked.
Dieldrin	Rat 60 Dog 68 Rabbit 45	Bluegill 3.4	Not been established in man. Impair liver function in animals occasional convulsions.	Hyperexcitability, tremors, ataxia, convulsions.
Lindane (Benzene hexachloride)	Rat 135 Dog 120 Rabbit 130	Rainbow trout 18	Liver necrosis in animals.	Vomiting and diarrhea, convulsions, circulatory failure.

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TABLE 38. (Continued)

Biocide	LD$_{50}$ (oral) mg/kg	48-hr TLm Values From Static Bioassay	Chronic Poisoning (to humans unless stated otherwise)	Acute Poisoning
Malathion	Rat 2500	Brooktrout 19.5	In animals, cholinesterase levels of red blood cells and plasma are reduced markedly.	Headache, tremors, nausea, abdominal cramps, diarrhea, coma, heat block.
Parthione	Rat 4	Bluegill 47	Not established in man.	Similar to those of malathione, but more severe and fatal.
2, 4-D‡	Mouse 375	Bluegill 800-2100	Weakness, fall of blood pressure, muscle damage.	Burning pain, painful and tender muscles, fever, paralysis, irreversible fall of blood pressure.
2, 4, 5-T§	Rat 300 Dog 100	Bluegill 560-16,700	Similar to 2, 4-D.	Similar to 2, 4-D.

* median lethal dose-the dose of a test material, ingested or injected, that kills 50% of a group of test organisms

† median tolerance limit-the concentration of a test material in a suitable diluent at which 50% are able to survive for a specific period of exposure

‡ 2,4-Dichlorophenoxyacetic acid

§ 2,4,5-Trichlorophenoxyacetic acid

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Disease can be defined as a state of abnormality that results from infection of a host (160). Many agents produce infections that give rise to illness only on occasion, though some agents are so virultent that virtually every infection will indicate some abnormality disease in the host.

Central to the issue of potential health risks of sludge landfilling is host susceptibility and immunity to sludge and refuse pathogens and the concept of infections dose. It is beyond the scope of this study to describe the various host/agent relationships, and despite their significance, most of them are as yet poorly understood. In general, it is known that less than a single biological unit (bacterial cell, viral particle, or protozoan cyst) of an agent may be capable of causing an infection. Also, the majority of enteric bacteria, viruses, and protozoan parasites show a high degree of species and tissue specificity in their infection habits. Thus, though ingestion of a disease agent may occur, the agent must work its way to a specific host environment for infecton to be initiated. Appendix C summarizes the specific dose/response relationship for various microorganisms and hosts.

Immunity, another major host factor, is acquired after experience with an infectious agent. Specificity and immunity are host factors effective in determining whether an infection takes place. Host "resistance", a poorly understood host characteristic, and in some cases immunity, will determine the course of an infection once it has begun.

In summary, the public health effects of sludge landfilling depend not only on the potential for contaminant transport from landfills to man, but on disease agent virulence and host response. Evidence shows that even less than one virus particle can cause infection in humans so there is little doubt as to the virulence of some agents. Infection, however, does not always lead to disease. This occurrence depends not only on the virulence of the agent and its dose size, but on host immunity and susceptibility.

EPIDEMIOLOGICAL EVIDENCE

The previous discussion has indicated that pathogenic organisms present in WWTP sludge and municipal refuse can remain viable in a landfill environment for varying lengths of time, and can be transported away from the landfill for reception by human hosts. Therefore, the potential exists for these pathogens to contribute to human disease, whether during transport of the sludge or refuse to the landfill, upon its placement, or after covering. In general, public health surveys and investigations conducted during sludge and refuse landfilling and sludge land spreading operations have shown little or no evidence of illness attributable to these land application

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activities.

For example, sludge landfilling codisposal demonstrations conducted by Stone (39) in 1973 resulted in no illnesses to landfill personnel which were attributable to landfilling operations. In addition, no illnesses were reported in a literature review or the nationwide survey on sludge disposal into municipal landfills conducted for the same investigation. An earlier investigation by Stone (1953), reported no particular difficulty with human disease transmission from land disposal of sewage wastes (230). A case study of eight sludge landfills by SCS Engineers (92) found no discernible increase in the frequency of illness by site employees, site users, or the community as a result of sewage sludge disposal operations. A systematic health study (231) of persons living on farms where anaerobically and aerobically digested sludge was applied revealed no unusual occurrences of acute gastrointestinal or respiratory illnesses. Salmonella spp. was isolated from both the sludge being applied and from 2 persons, one living on a sludge receiving farm and one on a control farm. However, the serotypes of the sludge isolates and the human isolates were different. But, during the first year, one person who had been negative on a pre-sludge tuberculin test had a slight reaction (< 5 mm diameter induration) when tested approximately 34 weeks after the first sludge application on their farm.

Methods of refuse and sludge handling and disposal probably has significant bearing on their associated health hazards. Based on limited epidemiological evidence of the health effects of handling solid wastes, the World Health Organizaton (WHO) found that improper handling adversely affects the health and welfare of the workers and the community (301). For example, 95% of the refuse workers in India showed stool specimens with selected parasites in comparison with approximately 4% in the control group (301). WHO points out that because refuse in the United States often contains fecal matter from pets and disposable diapers, the potential public health threat posed by raw refuse is increased (301). However, in spite of the hazards represented by municipal refuse, Ware (33) states that there is not a single epidemiological study which can directly trace outbreaks of disease to the presence of pathogens in municipal refuse. There is evidence (232) relating disease to water contamination by sewage sludge and animal manures.

The difference in public health risks posed by admixed sludge/refuse codisposal landfills and municipal refuse landfills is highly speculative. Previous discussion indicated that the chance of sludge pathogen transmission via aerosolization were minimal. Sludge addition to municipal refuse landfills may increase vector attraction (particularly flies) to the landfill, but evidence that flies are involved in the transmission of disease is generally lacking. Because refuse

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can be highly contaminated with pathogens, the risks of pathogen transmission via direct contact can be high for both sludge and refuse. Perhaps the only pathway in which health risks are increased for codisposal landfills in comparison with refuse-only landfills, is ground water. A municipal refuse landfill receiving sludge is likely to reach field capacity sooner than if no sludge were received, which may increase the possibility for viable contaminants to reach the ground-water table.

SUMMARY

The direct pathways for disease transmission from sludge landfilling operations include aerosols, vector transport, direct contact, ground water, and surface water runoff. The ground water and surface water runoff pathways present the greatest risk for disease transmission. The potential health effects and virulence of sludge and refuse contaminants have been outlined. The occurrence of disease in persons exposed to sludge landfilling or landspreading operations is generally absent, though systematic epidemiological surveys of these operations are lacking.

The addition of sludge to municipal refuse landfills is believed to increase the public health risk over refuse-only landfills primarily in its potential for increasing the chances for viable and non-viable toxic contaminants to enter ground and surface waters. The increased risk of ground and surface water contaminantion is caused by the increased landfill moisture provided by the sludge, which can: (1) accelerate attainment of landfill field capacity, or (2) promote leachate channeling through the refuse upon lift construction. Though the previous Section (Section 5) has shown that codisposal leachates may be of less strength than refuse-only leachates, contaminant concentrations of codisposal leachates are well above most water quality criteria and could seriously degrade ground and surface water quality.

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SECTION 7

AVAILABLE CONTROL TECHNOLOGY

Landfilling of WWTP sludge can be an acceptable disposal method provided environmental and public health impacts are controlled. Control technologies which can be implemented to protect the environment and public health can be divided into the following categories:

(1) Leachate and groundwater control, including collection, treatment, ultimate disposal, and monitoring;

(2) Surface water control, including run-on control and runoff retention and treatment;

(3) Air emissions control, including control of gases, odor, dust, and volatile sludge constituents;

(4) Erosion control, to limit wind and water erosion;

(5) Mud control, to prevent equipment from slipping or tracking mud;

(6) Vector and animal control, to limit vector access and to discourage burrowing animals;

(7) Aesthetics control, including site closure planning and visual barriers;

(8) Noise control, to prevent excessive noise; and

(9) Personnel health and safety control.

LEACHATE AND GROUNDWATER CONTROL

One of the primary criteria determining sludge landfilling feasibility and/or design for a given sludge on a particular site is a judgement or demonstration that the buried sludge will not pollute indigenous ground water. Background data accumulated during preliminary assessments of a site, including soils, geology, ground water, topography, and climate, can be used as a guide in developing the design and establishing certain management constraints. At this stage, it may be possible to determine whether a leachate/ground water isolation (subgrade liner) and leachate collection system would be needed. Such would be the case, for example, in an area where high ground-water table or near-to-surface bedrock conditions prevail. At sites where a subgrade liner is deemed unnecessary or questionable, assurances must be provided to protect ground-water resources. Theoretical models have been developed (233) which use background data on soils, ground water, etc., to define buffer zones around landfilling operations that allow for the natural attenuation of sludge leachate without threatening ground-water supplies. However, the interaction of system components is best determined by practical investigations using a set of tests and pilot studies applied on a case by case basis. In addition to establishing the feasibility of unlined landfilling methods, preliminary testing can show (234):

(1) The identity of sludge constituents which limit application rates;

(2) The assimilative capacity of soils for sludge constituents;

(3) Criteria for safe facility management;

(4) Monitoring parameters which will indicate contaminant migration into ground water, and surface water;

(5) The land area required to treat a given quantity of sludge; and

(6) The ultimate fate of sludge constituents.

Tests for the determination of leaching hazards include soil thin layer chromatography, soil leaching columns, and field soil leachate testing. Transport mechanisms of potential leachability are best assessed by soil thin-layer chromatography and column leaching techniques (234). However, where a sludge constituent is demonstrated to be leachable, field studies will be necessary to determine the leachate concentrations of the mobile constituents for establishing the maximum safe sludge application. Field pilot studies can also ascertain any unforeseen methodological, operational, or environmental problems (such as odors and vectors). Descriptions of each technique are presented in Appendix D.

For sludge disposal sites where ground-water degradation is deemed a potential problem, or where a problem already exists, leachate control measures can be divided into three classes (1) ground water/leachate isolation, (2) leachate plume control, and (3) surface water control. Technologies within each category are listed below:

- Ground-water/Leachate Isolation
    - Artificial Liners
    - Bottom Sealers
    - Slurry Trench
    - Grout Curtain
    - Sheet Piling Cutoff Wall

- Leachate Plume Control
    - Drains
    - Well Point Systems
    - Deep Well Systems

- Surface Water Control to Minimize Leachate Generation
    - Contour grading and surface water diversion
    - Surface sealing
    - Revegetation

Leachate control and ground-water management activities also include:

- Leachate treatment and ultimate disposal

- Ground-water monitoring

Each of these ground-water/leachate control techniques is discussed in the following text.

Ground-water/Leachate Isolation

Artificial Liners--

Artificial liners refer to those material other than native soils which are utilized for landfill sealing purposes. In their performance, liners function by two mechanisms (235):

(1) To impede the flow (flux) of the pollutant and pollutant carrier, usually, water, into the subsoil and ground water.

(2) To absorb or attenuate suspended or dissolved pollutants, whether inorganic or organic, in order to reduce the concentrations so that they fall within the ranges set by regulatory agencies for ground water.

Liners may consist of material such as synthetic membrane liners or natural soils having low permeability. Available liner materials are listed in Table 39. Membrane liners are the most impermeable of the liner materials, though they have little capacity to absorb leachate constituents. Conversely, natural soils such as clay have a large absorptive capacity and may have

TABLE 39. AVAILABLE TYPES OF LINERS* (235)

1. Clays
   - Kaolinite
   - Illite
   - Montmorillonite

2. Admixed Liners
   - Hydraulic asphalt concrete
   - Asphalt concrete
   - Soil cement
   - Soil asphalt

3. Synthetic Polymeric Membranes
   - Butyl rubber
   - Chlorinated polyethylene (CPE)
   - Chlorosulfonated polyethylene (CSPE)
   - Elasticized polyolefin
   - Epichlorohydrin
   - Ethylene propylene rubber (EPDM)
   - Flurocarbon polymers
   - Neoprene (chloroprene rubber)
   - Neoprene (chloroprene rubber)
   - Nitrile rubber (NTR)
   - Polybutylene (PB)
   - Polyester
   - Polyethylene - HDPE
                 - LDPE
   - Polyvinly Chloride (PVC)
   - Thermoplastic elastomer
   - Urethane

4. Sprayed-on Liners
   - Air-blown asphalt
   - Emulsified asphalt membranes
   - Urethane modified asphalt
   - Rubber and plastic latexes

5. Soil Sealants
   - Chemical (Soil amendments)
   - Lime
   - Rubber and plastic latexes
   - Polymeric emulsions

6. Chemical Absorptive Liners
   - Acidic and basic fly ash
   - Bottom ash
   - Activated alumina
   - Activated charcoal

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* This list is representative of current technology.

a permeability comparable to membrane liners. The flux of contaminants through soils can be significantly reduced by increasing the soil thickness or by applying various chemicals to the soil. Liner material which can be sprayed-on to existing soils include airblown asphalt, emulsified asphalt, urethane modified asphalt, rubber and plastics, and various chemical or latex soil sealants. In addition, a variety of admixed or formed-in-place liners have been used in the impoundment of water. These linings include asphalt, concrete, soil cement, and soil asphalt, all of which are hard-surface materials. The choice of liner material is dependent on numerous site and waste-specific factors, some of which are (235):

- Type of waste (i.e., sludge-only or codisposal) and composition;
- Required operating life of disposal facility;
- Required life of the liner after closure of the facility;
- Soils on or nearby site, including subsoil;
- Hydrology and ground water;
- Significant environmental factors;
- Acceptable flow out of impoundment;
- Permeability;
- Compatability tests of liner materials with waste(s);
- Costs of materials and their installation; and
- Reliability of materials, seams, joints, etc. and documented experience in the technology.

A comprehensive presentation of the selection, performance, installation, and maintenance of liners for specific containment situations is given by Matrecon, Inc. (235). Shultz and Miklas (236) also describe liner installation procedures. Ware and Jackson (237) list the various impermeable linings associated with several sanitary landfills, chemical and hazardous waste disposal sites, and holding ponds.

The compatability of a liner with a specific waste is one of the most important considerations in planning a landfill site. Compatability testing of sludge landfill leachates with liner materials is undocumented. However, the EPA sponsored a research program (238) to study the compatability of liner materials with sanitary landfill leachate. Table 40 summarizes the

TABLE 40. THE EFFECTS OF POLYMERIC MEMBRANE LINER IMMERSION IN LEACHATE FOR 8 MONTHS (238)

Polymer	No. of liners in test	Absorption of leachate, %	% Original value for unexposed membrane			Change in hardness, points
			Tensile strength	Elongation	S-200	
Butyl rubber	1	1-2	90-97	104-106	85-86	0
Chlorinated polyethylene	3	8-10	80-115	64-135	84-123	-5 to -1
Chlorosulfonated polyethylene	3	13-19	82-124	97-107	47-113	-20 to -4
Elasticized polyolefin	1	0.1	86-94	91-92	102-106	0
Ethylene propylene rubber	5	1-13.5	90-91	76-138	98-220	-1 to +2
Neoprene	4	1-19	69-100[a]	82-103[a]	79-102[a]	-11 to +5
Polybutylene	1	0.1	96-99	96-97	99-103	-3
Polyester elastomer	1	2.0	99-115	101-108	95-110	-4
Polyethylene	1	0.6	110-180	96-181	100-116	-7
Polyvinyl chloride	7	1-3	91-110	98-129	76-102	-2 to +1
Polyvinyl chloride + pitch	1	6.0	92	109-133	93-108[b]	-2

[a] Data on fabric-reinforced neoprene liner #42 were not included.

[b] S-100 - unexposed specimen broke at 150% elongation.

effects of immersion of various polymeric membrane liners in sanitary landfill leachate for eight months (238). The results showed that polyolefins, such as polyethylene, polybutylene, elasticized polyolefin, and polyester elastomer, swelled and softened the least. Polyvinyl chloride membranes also showed low swelling and little change in properties. Results were fairly consistent with those obtained for membrane liner materials exposed for one year in simulated landfills (239). The same study showed that admix liners containing asphalt, although experiencing a significant reduction in compressive strength, maintained their impermeability to leachate after one year in simulated landfills. Soil cement hardened considerably during the same exposure period, and its permeability decreased somewhat. Sprayed-on asphaltic membranes absorbed leachate slightly but other property changes were negligible after exposure to leachate for one year (239).

Costs can be a crucial factor in the ultimate choice of liner material for a given landfilling site. Capital costs can include extensive site preparation (e.g., rough grading, subgrade preparation, and surface smoothing) and costs associated with liner installation. In addition, leachate collection systems, liner covers, and possible ground-water monitoring and gas control systems can add significant capital costs. Tables 41 and 42 list the costs of various liner materials. Of the polymeric membranes, polyethylene (PE) and polyvinyl chloride (PVC) are the least expensive liner materials based on both delivered and installed 1977 costs. Of the admix materials and asphalt membrane liners, soil + bentonite, soil cements, soil asphalts, and spray-on asphalts are the least expensive to install, based on 1973 cost information (235).

Because of the possibility of liner leakage, placement of a small piece of the installed liner (coupon) in the fill may be used to evaluate the effects of the waste on the liner material properties over time intervals. Coupon placement should allow for essentially the same exposure to the waste and environmental conditions as the installed liner. Piping placed beneath liners can facilitate detection and collection of any leachate leakage. Underdrains consisting of clay, asphalt, and plastic have been incorporated into liner landfill sites to help implement this additional safety device. Another function of underdrains is to drain ground water, preventing pressure build-up and possible rupture of the liner in the event of a rising water table.

Proper management of a liner sludge disposal facility is essential to the performance of the landfill and to liner longevity. Regular inspections should be made of embankments and berms. Growth of vegetation must be controlled around the landfill perimeter to prevent liner damage from plant roots. Rodents, such as gophers, squirrels, rats, muskrats, and mice,

TABLE 41. COSTS OF FLEXIBLE POLYMERIC MEMBRANE, PLASTIC, AND RUBBER LINERS (235)

			1973		1977		1980
Material	Nominal thickness mils	Fabric reinforcement[a]	Price, fob, $/yd²	Installed cost[c] $/yd²	Delivered cost[b] $/yd²	Installed cost[c] $/yd²	Installed cost[c] $/yd²
Butyl Rubber	30	no	2.25	3.25-4.00	2.70-3.15	3.40-3.60	
		yes	...	...	2.79-3.24	...	...
Chlorinated polyethylene (CPE)	30	no	2.25	2.43-3.24	2.70-3.15	3.10-3.50	6.17[d,e]
		yes	...	...	2.79-3.24	3.24-3.78	...
Chlorosulfonated polyethylene (CSPE)	30	no			2.70-3.15	3.10-3.50	...
		yes	1.66	2.88-3.06	2.79-3.24	3.24-3.78	7.50-8.50[f,g]
Elasticized polyolefin (ELPO)	20	no	...	...	1.80	2.07-2.25	...
Ethylene propylene rubber (EPDM)							
covered	30	yes	2.00[h]	2.43-3.42	2.70	3.42-3.50	...
uncovered	30	yes	...	...	2.16	2.88	...
Neoprene (CR)	30	no	2.07	4.41-5.40	...	...	...
		yes	...	...	5.00	5.85-6.75	...
Polyethylene (PE)	10	no	0.36	0.90-1.44	0.60-0.70	1.10-1.40[i]	...
Polyvinyl chloride (PVC)	20	no	.90	1.17-2.16	1.11-1.53	1.44-1.98	...
	30	no	1.33	...	1.44-1.89	1.80-2.45	...

---

[a] Fabric reinforcement, usually nylon or polyester scrim.

[b] Delivered cost in dollars per square yard; cost of sheeting in panel - 5,000 to 150,000 sq ft.

[c] Installed cost is highly dependent on area being lined.

[d] 45 mil thickness, three ply, one ply polyester scrim.

[e] Engineering News Record, July 10, 1980, p. 61; does not include subgrade preparation of soil cover.

[f] 45 mil thickness, five ply, two ply polyester scrim.

[g] Winning bid, June 11, 1980, City of Seattle, North Beacon Reservoir Reline.

[h] The cost over the range of area of 150,000-500,000 sq ft is usually in the range of $0.05-0.06 per square foot

Soil cover: 1) $\$.10-.50/yd^2$/foot of depth
2) $.05-.07/ft^2$/foot of depth

[i] If tape is used, tape cost: $0.05-.06/linear foot

TABLE 42. COST ESTIMATES OF SOIL, ADMIX MATERIALS AND ASPHALT MEMBRANE LINERS (235)

Liner Type	Installed Cost Dollars Per Square Yard 1973	 1980
Soil + bentonite 9 lb/sq yd (1 psf)	$0.72	-
Soil cement 6-in thick + sealer (2 coats - each 0.25 gal/sq yd)	1.25	-
Soil asphalt 6-in thick + sealer (2 coats - each 0.25 gal/sq yd)	1.25	-
Asphalt concrete, dense-graded paving with sealer coat (hot mix, 4-in thick)	2.35 - 3.25	5.00 - 7.00
Asphalt concrete, hydraulic (hot mix, 4-in thick)	3.00 - 4.20	-
Bituminous seal (catalytically blown asphalt) 1 gal/sq yd	1.50 - 2.00 (with earth cover)	-
Asphalt emulsion on mat (polypropylene mat sprayed with asphalt emulsion)	1.26 - 1.27	-

may damage liner material. Provisions should be made during construction to control their impacts.

Bottom Sealers--

A bottom seal is a leachate/ground water control measure which can be implemented at existing landfill sites. The method involves creating a bowl-shaped seal beneath the site by pumping or pressure injecting grout through tubes placed through the fill at regular intervals (240). A variety of materials such as Portland cement, bentonite, or chemical grout can be used (240,241,242). Obviously, this method requires a detailed knowledge of both landfill boundaries and soil properties; extensive exploratory corings and soil testings are required. Grouting has been a standard practice for many years, though documented use in sludge and sanitary landfilling is lacking.

Bottom sealing has its limitations, the most significant of which is that methods of determining that all voids between boreholes have been effectively grouted are not available. Overdesign of the grout barrier is almost unavoidable because of barrier construction uncertainties. Also, since grouting is most effective in gravel and sand, the grout-take may be erratic when unchartered pockets of fine-grained soils are encountered (240).

The costs of constructing a grout bottom seal will vary depending on the permeability of the grouted materials. Tolman _et al_. (240) in 1978 reported the following construction costs for a 1.2 m (4 ft) thick Portland cement bottom sealer under a 4-hectare (10-acre) landfill: with 20% voids, $1,115,000 to $2,786,000; with 30% voids, $1,672,000 to $4,180,000.

Slurry-Trench--

A slurry-trench is a barrier to movement of underground water which may be used to prevent the horizontal subsurface movement of leachate from a landfill, or to divert ground-water flow beneath and away from the landfill. A properly designed cutoff wall lowers the water table so that it no longer flows through the landfill (240). Slurry-trench technology was developed for use in the construction industry and considerable literature exists describing this application (243-245) along with sanitary landfill applications (246).

Advantages of slurry-trenches include relatively simple construction methods, low maintenance once the cutoff wall is constructed, and an absence of bentonite barrier deterioration with age. Potential disadvantages associated with slurry-trenches include the cost of shipping bentonite and excessive costs due to excavation in rocky ground (240).

In 1980, the Los Angeles County Sanitation District planned (247) the construction of two subsurface slurry trenches downgradient from an existing sanitary landfill as a leachate collection device. The barrier was to be keyed into bedrock with a collection point, extraction well, and a downstream monitoring well. Cost estimates for facilities planning (e.g., leachate compatability testing, environmental impact reports, cost development, etc.) and geological tests were roughly \$20,000 and \$7,000, respectively.

Tolman et al. (240) estimated costs for slurry-trenching. A completed slurry-trench 18 m (60 ft) deep and 1 m (3 ft) wide will range from \$295-\$495 per linear foot based upon 1978 costs. Differences in price depend on whether the excavation is soil or rock and the type of bentonite slurry used. Emrich (248) proposed a slurry-trench cutoff wall 945 m (3100 ft) long and 44 m (145 ft) deep to help protect ground waters from a sanitary landfill in Windham, Connecticut. A cost range of 3 to 4.5 million dollars was proposed for the 10-ha (25-acre) site.

Grout Curtain--

A grout curtain performs a similar function as that of a slurry-trench in providing a barrier to either divert ground water flow around a landfill site or intercept migrating leachate. A grout curtain is created by injecting solutions under pressure into soils and underlying earth materials. The grout solution fills soil voids preventing the passage of leachates or ground water flow.

Grout materials include cement, bentonite, epoxy resins, silicone rubbers, lime, fly ash and bituminous compounds (240, 249). The use of a particular grout material is a function of soil characteristics encountered at the facility. American Cyanimid Co. has categorized the use of chemical grouts with various soil properties (250).

The variety of grout materials available in a particular situation will result in a disparity of costs. Tolman et al. (240) in 1978 found Portland cement to be the least expensive grout material; estimated costs ranged from \$142 and \$357 per m^3 (\$4.00 and \$10.00 per ft^3 based on 1978 dollars). They also estimated that a 518-m (1700-lineal ft) Portland cement grout curtain upgradient of a 4-hectare (10 acre) landfill to a depth of 18 m (60 ft) would cost between \$801,300 and \$1,003,000 based on 1978 dollars.

Grouting technology is well developed and is applicable to a wide range of soil properties. However, grouting is usually considered effective only in soils with permeabilities of 10^{-5} 10^{-5} cm/sec or greater. Grouting offers a useful approach in consolidated or cohensionless soils although costs may be prohibitive for large codisposal sites. The use of grout curtains for diverting ground water around landfills or intercepting leachates is undocumented, although the principle is sound for landfilling practices.

Sheet Piling Cutoff Wall--

A sheet piling cutoff wall may be useful in preventing ground water flow through a landfill site, though the literature has not reported its use. A sheet piling cutoff wall involves drawing lengths of steel sheet piling permanently into the ground to retard the flow of leachate or water near the landfill. Sheet piling is readily available in various shapes and weights, the selection of which is based on costs and ease of installation. The sheet piling is assembled before being driven into the ground (240). The sheet piling wall is not watertight due to mill tolerances in the interlocking edges (240). Cathodic protection can prolong the useful life of the wall, which can range to over 40 years (240).

Tolman _et_ _al_. (240) developed costs for a 518 m (1700 ft) long and 18 m (60 ft) deep cutoff wall. Total costs to construct and install a 20 ton sheet piling cutoff wall (including shipping costs from Buffalo, New York to Philadelphia) were estimated to be between $650,000 to $956,000 in 1978.

Sheep piling cutoff approaches offer several distinct advantages over slurry trenches and grout curtains. Among these are ease of construction (no excavation is necessary), availability of contractors to perform the work, the maintenance free nature of the wall, and economical construction costs. Limitations of the sheet piling wall include problems of driving the sheet through rocky ground and its corrosion potential.

Leachate Plume Control

Leachate plume control refers to those efforts to prevent a contaminated ground-water body from contacting additional ground-water or surface water resources. Methods involve the removal of water by pumping or drainage from around the landfill. Leachate plume control is similar in purpose to subsurface infiltration barriers by effecting changes in water table elevations, and are often used in conjunction with subsurface barriers. The control measures differ insofar as a continuing input of energy is usually required for pumping water. Plume management measures used with or without subsurface barriers involve leachate collection and handling.

Drains--

The purpose of ground-water drains is to intercept near-to-surface ground water which can then be redirected and treated. Drains are constructed by excavating a trench to a desired depth, partially backfilling the trench with highly permeable sand or gravel, placing a plastic or ceramic drain tile in the sand and gravel bed, and complete the backfilling. The drainage can be collected in an impermeable sump and directed or pumped back to the landfill.

Cases have been reported on ground-water drain installations placed upgradient from sludge burial sites in order to redirect near to surface ground water around the landfills. Walker et al. (82) described the use of a flexible slotted drain tile within a trench upgradient from a sludge entrenchment facility. The average depth of the tile was approximately 1 meter below the soil surface. The tile functioned well in carrying off excess water. Estimated installed costs (1978 dollars) were reported as $2,000/hectare ($800/acre). Drainage costs were estimated to range from $750 to $2,000/hectare ($300 to $800/acre) when installed by professionals specializing in lazer-guided trenching machines. Tolman et al. (240) estimated similar installment costs for ground-water drains; labor and maintenance costs were estimated to be $1,545 per year for a 4-ha (10-acre) landfill, based on 1978 costs.

Well Point Systems--

Well point systems can be used to lower the water table several feet and/or to collect landfill leachate. Well points are short lengths of plastic (PVC) or teflon well screen which can be placed in the saturated zone up or downgradient from the fill. The well points are connected to a pump which evacuates the air from well points creating a vacuum which forces the ground water to flow through the well points. They can provide drawdowns of up to 4.5 m (15 ft) in their immediate vicinity (252). Spacing of the well points and discharge of the pumped waters are determined by the individual site characteristics (240).

The advantages of well points are that installation costs are moderate and the construction methods are relatively simple (personal communication, Bob Timmons, Timco Geotechnical Products). The disadvantage of this system is that power costs can be high, continued maintenance is necessary, and long term financial commitment is required.

Well point systems are estimated to cost between $30 to $33/m ($9 to $10 per lineal drain ft) for installation plus $2,000 to $3,000 for a 19 to 24-liter/sec (300-400 gal/min) pump (240), based on 1978 dollars. To drain a 225-m (900-lineal-ft) area upgradient from a landfill would cost approximately $12,000 (capital cost), plus costs of electrical energy, pretesting, pretest analyses, and system design and engineering (240). Total capital and operational costs in the initial year would range between $180,000-$190,000 for a 275-m (900-lineal-ft) well point system (240).

Deep Well Systems--

Deep well withdrawal refers to an installation in which a

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greater vertical depth of water is removed than for a well point system. Deep wells are capable of lowering the water table as much as 12 m (40 ft) in uniform sand (240). Each well is equipped with its own pump and is therefore capable of dewatering large areas.

Deep well dewatering systems generally require a higher initial investment than well point systems, since they require more materials, equipment, and greater installation costs. Tolman et al. (240) in 1978 estimated costs of $50 per m ($15 per ft) for a 10 cm (4 in) PVC well; a screen may cost $100 and a pump $800 to $1,000 (253). Capital costs for a well system 8 m (60 ft) deep to dewater a 275 m (900 ft) front was estimated to cost approximately $18,000 (240) in 1978. Electric power costs were estimated to be $10,500/yr (1978 dollars) based upon a 32 kw (24 hp) demand at $.07 per kwh (240). Like well point systems, pretesting, pretest analyses, and system design and engineering costs must be considered.

Emrich et al. (248) proposed a deep well dewatering system to lower the water table surrounding a sanitary landfill. Estimated capital costs for a ring of 80 wells, 19.5 m (65 ft) deep, generating 25.1 l/sec (400 gpm) were $160,000 in 1980; operation and maintenance costs for such a system were estimated at $14,000 to $15,000 per year. Added to this would be the cost for the disposal of the contaminated ground water, which would entail treatment costs.

Surface Water Control To Minimize Leachate Generation

Though sludge moisture can act as a major source of leachate at sludge landfills, the volume of water infiltrating through the landfill surface can also contribute to leachate formation. By utilizing control measures to minimize the quantity of water entering the landfill via rainfall or runon, leachate generation can be reduced. This section presents three methods of reducing infiltration.

Contour Grading and Surface Water Diversion--

Contour grading operations are used to increase the slope of the final cover, resulting in increased rainfall runoff and decreased infiltration of water through the surface of the landfill. Since erosion also increases with an increasing slope, the design of the slope should balance opposing considerations (where percolation is undesirable). On slopes of less than 3%, the irregularities of surface and vegetation commonly act as traps for detention of runoff (254). The value of 5% has been suggested and used in ground maintenance (84) as a first approximation of a slope sufficient to promote runoff without risking excessive erosion. However, designing slopes greater than 5% may be necessary where settlement can compromise surface slopes.

Ideally, to minimize overland routing in areas subject to infiltration, the center of the landfill should be the highest elevation (240).

Soils used for final cover require careful evaluation. Clearly, one of the most useful means of designing a surface to impede the passage of water to the sludge cells is to use a fine grained soil (clay or silty loams) of low permeability. If fine soil is not available, soil blending, membranes, or barriers may be necessary. Such criteria as permeability, erodibility, fertility, and suitability of the ultimate use of the completed site must be investigated and documented.

Soil layering can achieve effects not obtainable with a single material (129). A two layer system should be sufficient for most covers--a lower layer of compacted clay of low permeability, and a top layer of silty sand to support vegetation. Such an approach can also increase cover thickness, thereby increasing water storage capacity with subsequent retardation of percolation, and reduce effects of cracks and landfill settlements.

Contour grading operations are simple and economical. Tolman _et al_. (240) estimated a range of \$126,000 to \$242,000 for a 4-hectare (10-acre) hypothetical landfill of 0.6 m (2 ft) minimum thickness, in which cover material was transported from a borrow pit 9 km (5 miles) away.

Surface water diversion ditches intercept and direct all water from outside the immediate area. Interception is accomplished by constructing a ditch or system of ditches along the uphill sides of a landfill. Drainage ditches should be designed to accomodate a 10 year storm (255). To prevent erosion, ditches should be flat bottomed and grassed, with a ditch slope of 2% (84). Figure 33 presents some design specifications for surface and interceptor ditches.

Cost estimates by Tolman _et al_. (240) for a 0.6 m (2 ft) deep and a 1 m (3ft) wide trench ranged from \$37.50 to \$60.00 per m (\$11.30 to \$18.10 per ft) in 1978. Included in this figure was an assumed cost of \$7.80 to \$11.70/m^3 (\$6.00 to \$9.00/yd^3) for trench excavation.

Surface Sealing--

Surface sealing is a method by which an impermeable material is used to cap or seal a landfill, preventing water infiltration and minimizing leachate generation. Caps and seals can be constructed of clays, fly ash, soils, soil-cement, lime-stabilized soil, membrane liners, bituminous concrete, and asphalt/tar materials (129). Membrane and asphalt compounds may require an earth cover to protect the cover seal and to provide support (240). Lutton _et al_. (129) provide a

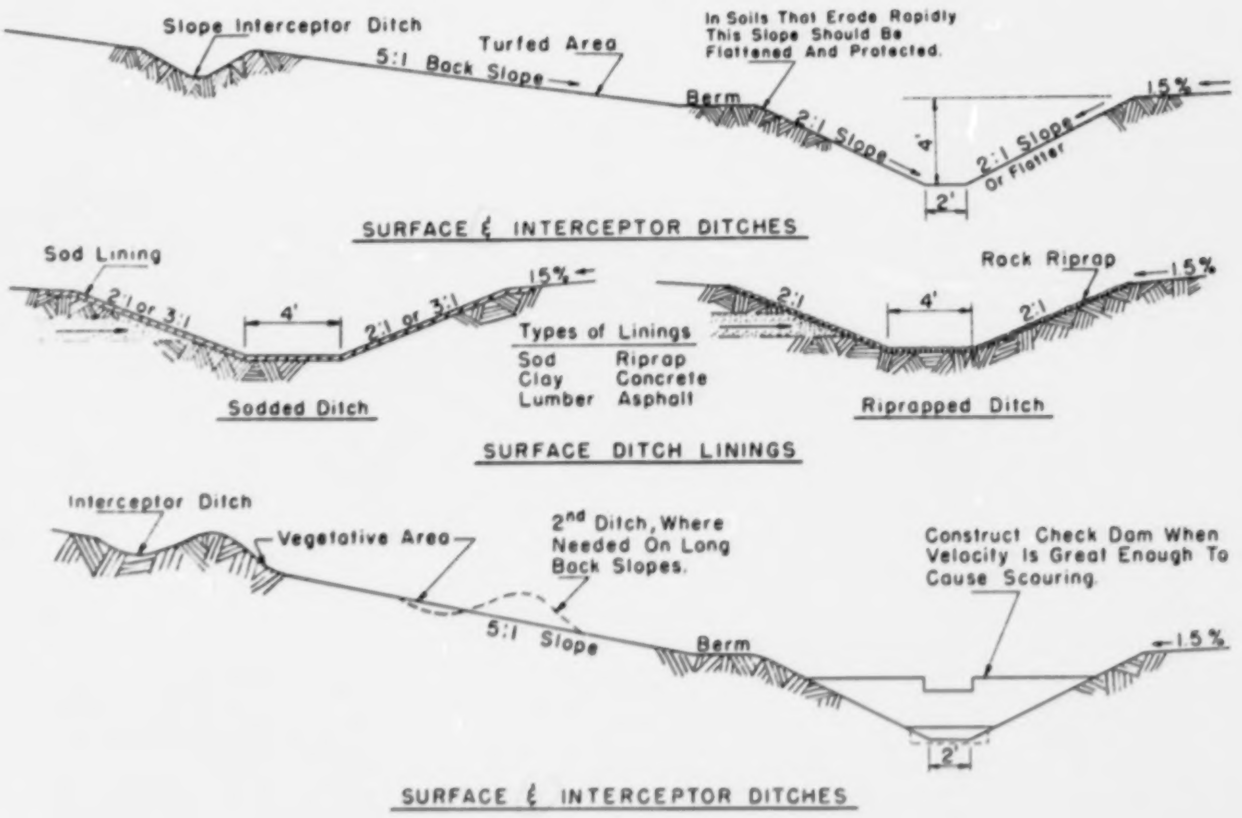
Slope Interceptor Ditch
Turfed Area
5:1 Back Slope
In Soils That Erode Rapidly This Slope Should Be Flattened And Protected.
Berm
2:1 Slope
4'
2'
2:1 Slope Or Flatter
1.5%
SURFACE & INTERCEPTOR DITCHES
Sod Lining
2:1 or 3:1
4'
2:1 or 3:1
15%
Sodded Ditch
Types of Linings
Sod Riprap
Clay Concrete
Lumber Asphalt
2:1
4'
2:1
Rock Riprap
1.5%
Riprapped Ditch
SURFACE DITCH LININGS
Interceptor Ditch
Vegetative Area
2nd Ditch, Where Needed On Long Back Slopes.
5:1 Slope
Berm
Construct Check Dam When Velocity Is Great Enough To Cause Scouring.
1.5%
2'
SURFACE & INTERCEPTOR DITCHES

Figure 33. Design specifications for surface and interceptor ditches (129).

comprehensive discussion of the design and construction of covers for landfills. In addition to the above-mentioned materials, 114 chemical additives which may be mixed with a soil cover for various beneficial effects (e.g., stabilization, repel water or resist water erosion, or resist dusting or wind erosion) are presented.

The sealed and covered landfill must be revegetated to stabilize the cover and minimize infiltration. If the cover material used is of low permeability, an underdrain system may be required to ensure lateral drainage above the seal (240). Locally, infiltration barriers will serve beneficially as gas and odor barriers, though some type of gas venting must be provided to allow escape of gases formed by sludge (or refuse) decomposition.

Costs for landfill sealing depends upon the amount of earthmoving and grading as well as the selection of seal materials. Tolman et al. (240) developed costs for landfill covers for a variety of seal materials for a 4-hectare (10-acre) site. These are listed in Table 43.

Revegetation--

Establishment of revegetation on landfill soil cover can help minimize erosion by wind and water. Revegetation can strengthen the soil mass with root and leaf fibers, and can reduce water runoff (129). By reducing water runoff; however, more water will enter the soil. This increased infiltration is offset at least partly by transpiration from vegetation, though there is considerable question with regard to the relative importance of these offsetting processes (132,256). A subsidiary benefit is that revegetation enhances the appearance of the landfill site.

The selection of the best revegetative cover for a particular site depends upon soil type, nutrient and pH levels, climate, and knowledge of plants that have the desired characteristics (257). If soils do not possess sufficient nutrients to support vigorous plant growth, sludge might be used as a soil conditioner. Bennett and Donahue (257) and Lutton et al. (129) provide comprehensive descriptions of revegetation practices. Many species of grasses and legumes are used for revegetation. Commonly used species are described in Table 44.

One of the disadvantages of revegetation is that an impervious clay or plastic barrier incorporated in the cover makes the plant-root zone susceptible to swamping after moderate rains since verticle drainage is impeded (129). Irrigation may be necessary during prolonged dry spells to prevent loss of plant cover. Also, revegetation may be damaged by landfill gases which continue to vent for years after site closure (258).

TABLE 43. COSTS OF SURFACE SEALS FOR A 4-HECTARE (10-ACRE) LANDFILL (240)

Material	Thickness (cm)	- 1978 - Cost Range ($)*
Clay Cap	15	140,100 - 256,200
Clay Cap	46	180,400 - 328,700
Bituminous Concrete Cap	4	192,500 - 340,800
Bituminous Concrete Cap	13	289,300 - 437,600
Fly-Ash Cap	30	136,100 - 247,300
Fly-Ash Cap	60	179,600 - 334,400
Soil Cement	13	209,440 - 321,400
Lime Stabilized Cap	30	209,440 - 321,440
PVC Membrane Cap	30 mil	388,800 - 575,500

* Cost estimates reflect land preparation costs for cover placement, including:

- excavation of 26,700 m^3 (34,950 yd^3) of common borrow material;
- excavation of 7,700 m^3 (10,000 yd^3) of the waste during grading operations; and
- earthmoving operations, grading and compacting materials, equipment and procedures for constructing each seal (estimated at $1,000 per acre).

TABLE 44. GRASSES AND LEGUMES COMMONLY USED FOR REVEGETATION (259)

Variety	Best Seeding Time	Important Characteristics	Areas/Conditions of Adaptation
Grasses			
Redtop bentgrass	Fall	Strong, rhizomatous roots, perennial	Wet, acid soils, warm season
Smooth bromegrass	Spring	Long-lived perennial	Damp, cool summers, drought resistant
Field bromegrass	Spring	Annual, fibrous roots, winter rapid growth	Cornbelt eastward
Kentucky bluegrass	Fall	Alkaline soils, rapid grower, perennial	North, humid, U.S. south to Tennessee
Tall fescue	Fall	Slow to establish, long-lived perennial, good seeder	Widely adapted, damp soils
Meadow fescue	Fall	Smaller than tall, susceptible to leaf rust	Cool to warm regions, widely adapted
Orchard grass	Spring	More heat tolerant but less cold resistant than smooth bromegrass or Kentucky bluegrass	Temperate U. S.
Annual ryegrass	Fall	Not winter hardy, poor dry land grass	Moist southern U. S.
Timothy	Fall	Shallow roots, bunch grass	Northern U. S., cool, humid areas
Reed canarygrass	Late summer	Tall coarse, sod former, perennial, resists flooding and drought	Northern U. S., wet, cool areas
Legumes			
Alfalfa (many varieties)	Late summer	Good on alkaline loam, requires good management	Widely adapted
Birdsfoot trefoil	Spring	Good on infertile soils, tolerant to acid soils	Moist, temperate U.S.
Sweet clover	Spring	Good pioneer on non-acid soils	Widely adapted
Red clover	Early spring	Not drought resistant, tolerant to acid soils	Cool, moist areas
Alsike clover	Early spring	Similar to red clover	Cool, moist areas
Korean lespedeza	Early spring	Annual, widely adapted	Southern, U. S.
Sericea lespedeza	Early spring	Perennial, tall erect plant, widely adapted	Southern. U. S.
Hairy vetch	Fall	Winter annual, survives below $0^{\circ}F$, widely adapted	All of U. S.
White clover	Early fall	World-wide, many varieties, does well on moist, acid soils	All of U. S.
Crownvetch	Early fall	Perennial, creeping stems and rhizomes, acid tolerant	Northern U. S.

Tolman et al. (240) prepared costs for revegetating a completed landfill with a mixture of 45% preinnoculated crown vetch and 55% annual rye grass. Based upon a slope of less than 12% and a number of seeding and cover soil preparation assumptions, costs of \$0.23 to \$0.18 per m^2 (\$.10 to \$.15 per yd^2) for 1978 dollars were developed. For slopes of over 12%, cost estimates ranging from \$0.23 to \$0.18 per m^2 (\$.10 to \$.15 per yd^2) were cited. From these cost estimates, Tolman et al. (240) derived a cost range of \$7,300 to \$12,000 for a 4-hectare (10-acre) landfill.

Leachate Treatment and Ultimate Disposal

Leachate collected by drainage ditches, well points, or deep well systems should be channeled into a retention pond(s) normally located in the lowest corner of the facility. Ponds and retention basins need to be designed to hold not only leachates, but expected surface runoff from a 24 hour 25 year return period storm (260). All sizing calculations should account for potential carryover of excess water accumulated during previous rainy spells. Retention basins need to be lined with compacted clay or a synthetic membrane having a permeability of 10^{-7} cm/sec or less (260). Every pond or basin must have an emergency or flood spillway, preferably with vegetative cover.

Leachate collected in the basins can be treated or disposed of by one of several methods. If the plant or company owns and operates a wastewater treatment plant on site, the leachate/runoff water can be pumped to the plant, treated, and disposed of via the wastewater treatment facility permit. Care must be taken that this added volume of water does not overwhelm the treatment plant. Also, research has demonstrated that high strength sanitary landfill leachates may compromise the efficiency of various unit treatment processes of a wastewater treatment plant (261,262). Laboratory scale tests performed by Ho et al. (261) demonstrated that sanitary landfill leachate (leachate COD = 10,000 mg/l) added to domestic wastewater in an extended aeration activated sludge plant may impair effluent quality for inflow volumes of greater than 5%. Chian and DeWalle (262) reported similar results for a maximum leachate inflow of 4% by volume.

Where the option of using an existing wastewater treatment facility is not a viable alternative, an NPDES (National Pollutant Discharge Elimination System) permit may be applied for. This would allow direct discharge of the leachate/runoff water after collecton if it met the NPDES water quality standards.

Another alternative for leachate/runoff water treatment is to dispose of the water internally in the landfill facility. The water may be "recycled" back to the landfill, or it may be sprayed in the air above the pond to enhance evaporation if no volatile or aerosol hazards would result. The use of nozzles that form large droplets helps minimize spray drift and any aerosol effects. Giddings (263) cited the use of a leachate holding lagoon which was aerated with floating fan aerators from which the leachate is recirculated back into the landfill.

Recycling of leachate back to the fill has been shown to accelerate the stabilization of refuse in a landfill (264,265), and should provide similar results for unstabilized sludges. The three most widely used recycling methods are:

(1) Spray irrigation - spray nozzles are placed at 15 to 30 m (50 - 100 ft) intervals on the landfill, and effluent is periodically pumped through them onto the landfill surface. These systems can be ten times as costly as the following systems due to power costs (266).

(2) Overland irrigation - an inexpensive, well-developed agricultural technique that uses trenches, spreading basins, or gated pipe to spread effluent (266).

(3) Subgrade irrigation - leachate passes through subgrade tile field or wells, and has the advantage of avoiding local odor and aerosol problems. Initial costs may be greater than the other two methods but, operationally, costs are comparable to overland irrigation (266).

Tolman et al. (240) estimates capital costs for leachate spreading systems to range from $1,235 to $7,500 per hectare ($500 to $3,000 per acre) depending on the use of open trenches, spray irrigation, or buried pipe (1978 dollars).

Finally, a number of studies have been conducted which examine the treatment efficiency of unit processes designated specifically for refuse landfill leachate. Chian and DeWalle (267) performed an extensive literature survey dealing with treatment methods for landfill leachates. They concluded that newly formed landfill leachate is best treated by aerobic or anaerobic biological treatment processes. Leachate from stabilized landfills or leachate with low organic contents are best treated with physical-chemical treatment methods. Steiner et al. (268) found the sequence of chemical/physical treatment (lime precipitation, sedimentation, ammonia stripping and neutralization) followed by an activated sludge process to be the most effective method for treating a variety of landfill leachates. 45✓ A summary of potential leachate treatment processes for specific leachate constituents is presented in Table 45. Treatment facilities constructed solely for sanitary landfill leachate are seldom employed.

(and) followed by an activated sludge process to be the most effective

TABLE 45. POTENTIAL TREATMENT PROCESSES APPLICABLE TO SLUDGE LEACHATES AND RUNOFF

Leachate Constituent	Raw Leachate* (mg/l)	Discharge Standard† (mg/l)	Removal Efficiency Required (%)	Potential Treatment Processes to Yield Required Efficiency
BOD_5	10,000-12,000	100	99-99.2	Activated Carbon or Reverse Osmosis Treatment of Biological Treatment Effluent
COD	18,000-20,000	‡	--	"
Ammonia -N	800-1,000	35	96-97.5	Ammonia Stripping or Activated Sludge
Cadmium	0.4-0.8	0.02	95-97.5	Lime Coagulation
Copper	5-10	0.2	96-98	Activated Carbon, Anaerobic Filter
Iron	300-500	7.0	97.7-98.6	Lime Coagulation, Anaerobic Filter, Aerated Lagoon
Nickel	0.8-1.0	‡	--	--
Zinc	10-20	0.6	94-97	Lime Coagulation, Anaerobic Filter, Aerated Lagoon

* Hypothetical, based on data reviewed in Section 5

† Developed by the Pennsylvania Department of Env. Res. and The Delaware River Basin Commission for Discharge to the Delaware River

‡ No discharge standard for this parameter

Ground-Water Monitoring

A ground-water monitoring program is an essential component of any sludge landfill operation, to assure that irreparable damage to the aquifer does not occur. As a supplement to ground-water monitoring, installation and maintenance of an unsaturated zone (i.e., above water table and beneath fill area) collection system should be performed so that one can measure the concentration of constituents before they reach the ground water. A contamination problem first detected in leachate water may prompt remedial actions. Ground water can then be monitored for the same problem. It is through the successful combination of these two systems that accurate monitoring of vertically moving constituents can be achieved. Unsaturated zone and ground-water samples should at a minimum be analyzed for heavy metals, pH, TOC, total and fecal coliform bacteria (for non-sterile sludges), and nitrate nitrogen (28,269,270).

SURFACE WATER CONTROL

Besides ground water, surface water runoff is a primary means by which pollutants can be transported off-site. Contaminants may either be dissolved or suspended in runoff and subsequently carried to surface waters or off-site land surfaces and vegetation. Therefore, surface water control is of primary importance in sludge landfill design and operations. It is imperative that sludge be covered whenever possible, and that adequate soil cover is applied to prevent sludge exposure from slumping or settlement. Dikes should be inspected regularly. Water management must limit the amount of water which contacts filled areas by controlling "run-off" from unfilled areas in order to minimize the potential for uncontrolled release of contaminated waters. Additionally, runoff from the filled areas must be collected and treated prior to release unless such runoff is shown to be free of contamination by sludge constituents.

The primary function of diversion structures on a sludge landfill is to intercept and change the flow of surface water. For a sludge landfill to function properly, it needs to be hydrologically isolated. This means that if the filled area lies downslope, all clean runoff originating from above the filled area needs to be diverted around the filled area. This is normally accomplished by constructing a berm of moderately compacted native soil around the filled area. The berm should run at an angle up the slope so that water moving downslope will be intercepted and moved laterally. This design will minimize ponding of water behind the berm and also allow a smaller berm to be constructed. If the area draining to the berm is large, a terrace or set of terraces may be needed above the berm to slow the velocity of the water and assist in lateral movement. All terraces and the diversion berm should discharge into a grassed waterway of sufficient size to be able to safely carry off the runoff water without serious erosion. For similar reasons, the terraces and diversion structures should be revegetated as soon as possible after construction.

Diversion structures can also be used to prevent contaminated water from leaving the site. In this case, waters flowing from upland portions of the sludge landfill would be prevented from lateral flow and directed downhill to a collection pond for treatment. Diversion structures may also be of use within the landfill to divide the facility into units or cells. Thus, sludge applications could be made to one cell for a time and then switched to a second cell.

All surface runoff should be directed to a retention pond such as that described in LEACHATE CONTROL. Treatment of runoff water should generally follow the guidelines put forth for leachates.

All water movement on a sludge landfill needs to be carefully planned. Smaller, more frequent sludge applications are better than a few very large volume applications. In this way, the potential runoff from unforeseen events such as storms or flash floods would be minimized. Any sludge application procedures or mixing procedures that result in soil disturbance or destroy terraces should be carefully planned. Finally, landfill operators should endeavor to provide sufficient basin storage capacity for the anticipated rainfall runoff during any wet season. Consideration must be given to other sources of basin water (e.g., leachates), required retention times prior to treatment or discharge, and discharge intervals.

During the operation of any sludge landfill, there will be periods during which application of sludge may not be possible due to wetness, low temperature, equipment failure, or other causes. Suitable facilities must be provided to retain sludge as it is generated until landfilling can be resumed. Design of the necessary structure will depend on the sludge characteristics - primarily, the sludge solids content. The actual size will depend on numerous factors, including:

(1) Waste generated during extended wet periods;

(2) Waste generated during periods of extended cold weather;

(3) Wastes generated during site excavations and construction;

(4) Wastes generated during periods of equipment failure; and

(5) Wastes generated in excess of application rates due to seasonal fluctuations.

The design of sludge storage facilities must insure that runoff and leachates generated during storage are retained. Sludges can be conveniently stored in clay lined ponds or basins as discussed in LEACHATE CONTROL. Another approach to allow continued application during periods of inclement weather is to construct all weather roads on the site in such a pattern that a truck or spray rig could discharge wastes to the sides into the disposal area. Burial of sludges discharged in this manner will be necessary as soon as soil conditions permit. Proper grading and diversion ditches must be maintained during these periods to prevent runoff hazards.

AIR EMISSION CONTROL

Air quality can be impaired by sludge landfilling practices if excessive gases, odors, or volatiles are emitted during storage, handling, or disposal. The emission of aerosols has been receiving increased attention. Pathogens present in aerosols must be considered a potential source of disease and infection because municipal wastewater aerosols have been found to include enterobacteria, enteroviruses, and coliphages (178). Excessive dust from traffic, excavation, and burial can also be a problem. Corrective measures should be taken to avoid such problems.

Gas

The decomposition of sludge organics produces gases, predominately methane and carbon dioxide. Other gases may include nitrogen and oxygen, and traces of ammonia, hydrogen sulfide, hydrogen, and volatile organic species. The amount and composition of gases produced depends on the quantity and characteristics of sludge deposited, the sludge moisture present, sludge age, and other factors (28).

The migration of methane gas around sludge landfills constitutes a hazard in that the gas may accumulate to explosive concentrations in buildings adjacent to the landfill. The gas forms an explosive mixture in the range of 5% to 15% methane in air. Previous research (271) has provided an analytical technique for predicting the time concentration profiles for methane around sanitary landfills. Computer programs (272) are available for studying site specific situations, and design charts (273) based on simplifying assumptions may be used to estimate distances of migration for planning purposes.

Current control technology to mitigate potential methane migration from a sludge or codisposal landfill site can be divided into four classes. These are (143):

(1) Trench vents - trenches are continuously cut around the landfill and filled with coarse gravel. Such vents may vent naturally to the atmosphere or may undergo forced convection by mechanical pumping into or out of the trench.

(2) Pipe vents - similar to trenches except that they are placed at intervals around the landfills. Normally some type of convective flow must be used if such pipe vents are to be effective.

(3) Barriers - constructed similarly to trench vents except that the trenches are filled with saturated compacted clays or other impervious liner materials.

(4) Hybrid systems - a combination of trench vents backed by impervious barriers. The trench vent may or may not involve forced flow.

More complete descriptions of gas migration control devices and design approaches are provided by Moore and Rai (143) and Moore (274). It should be noted that pipe vents and hybrid systems may not be suitable for sludge landfills because the high moisture content typically found in sludge does not permit gas movement and sludge can enter and clog the evacuation pipes.

Gas recovery systems at sludge landfills has not been documented, though the technology is well developed for refuse landfills. Many sludge landfilling operations are considered too small to be economically feasible for gas recovery (28).

Odors

Obnoxious odors are commonly associated with WWTP sludges, representing a potential serious problem at a sludge landfill unless preventative steps are taken. Inorganic gases and organic vapors result from biological activity. The more common malodorous inorganic gases associated with WWTP sludges include hydrogen sulfide, sulfur dioxide, and ammonia. The most frequently emitted organic odors include methymercaptans, methyl sulfides, amines, indole, and skatole (136). While odor does not indicate that a sludge landfill is malfunctioning or that environmental damage is occurring (other than the odor), it may become a problem that is serious enough to prevent landfilling of sludge at a site which is otherwise ideally suited for this purpose.

The potential odor problem should be taken into account when a disposal site is selected. Proximity to housing and thoroughfares as well as prevailing wind direction should be considered. The frequency and severity of inversions which may tend to trap malodorous gases should also be evaluated. Ideally, isolated sites should be selected, but in some cases this is not possible and locations adjacent to wastewater treatment plants, which may be near public areas, must be used. In such cases, certain steps can be taken to minimize odor problems.

Perhaps the best method to mitigate odor problems is to cover the sludge as frequently as necessary. The soil has a large capacity to absorb gases. Sludge storage should be minimized.

Lime or chemical agents can be applied to sludge or soils to reduce odor problems. Chemicals may include disinfectants which act as biocides (such as lime), chemical oxidants which may act as biocides and which may also supply oxygen to the microbial population, and masking agents which impart a more acceptable odor which overpowers the undesirable odors. Hydrogen peroxide is a commonly used biocide and oxidizing agent. Pountney and Turner (275) have reported success utilizing hydrogen peroxide to control hydrogen sulfide odors in wastewater treatment facilities. Strunk (276) suggests that hydrogen peroxide acts primarily by oxidizing reduced sulfur compounds. In a study testing the effectiveness of twenty-two commercial odor controlling products, chlorine, mechanical mixing, waste oil, wintergreen oil and activated charcoal, Warburton et al. (277) reported that only mechanical mixing and chlorination significantly reduced odor from swine manure. Thus, while it is possible that some commercial products may be effective in reduction of odors from certain wastes, alternate means including soil cover or oxidizing agents should be considered first.

Odor controlling chemicals have been applied either by direct incorporation into the sludge prior to application, by manual or solid set spraying along borders or over entire areas, or by point spraying, which might be done through a manifold mounted on the rear of the machine used to spread or place the sludge. Before an odor controlling chemical is employed, biological testing must demonstrate that it does not inhibit the sludge-degrading microbial population (28).

Volatiles

Like odors, sludge volatiles are believed to be best controlled through regular soil cover application, and by minimizing sludge storage intervals.

Dust

Dust problems can occur on access roads near the site and during many activities inherent with sludge landfilling, including site preparation, excavations, sludge/soil mixing operations, and soil cover placement. Dust may be controlled

Excessive watering may promote leachate formation

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by periodic light watering. Excessive watering may promote leachate formation. A good source of water is the accumulated surface runoff. Access roads should be graveled. For areas covered with interim or final cover soil, vegetation should be established.

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The use of chemicals and waste oil is reported as a dust control measure (279). Waste oil has some air pollution potential, but when restricted to relatively small landfilling operations, use of waste oil is predominantly beneficial (129). Preliminary experimentation is necessary to determine additive toxicity, duration of effectiveness, stability, cost, etc. (278). Extended use of chemicals for dust control may be detrimental to runoff water quality.

EROSION CONTROL

The control of water and wind erosion at a sludge landfill is necessary to prevent exposure of the sludge, loss of valuable soil, and to prevent contaminants from moving off site. Soil conservation methods develped by the USDA (279,280) are well suited to control erosion of agricultural fields and can readily be adopted for use at sludge landfilling sites. Wind erosion may be a particular problem in dry seasons or arid regions, but maintenance of a vegetative cover and a moist soil should lessen such losses.

Sloping land used for sludge landfills should be provided with terraces and grass waterways to control the runoff of water and to minimize the potential for erosion. Terracing is the construction of benches or broad channels across a slope, such as those diagrammed in Figure 34. The number of terraces is governed by the slope, soil type, and vegetative cover (260). Terraces will slow the flow of intensive storm water off the sludge landfill, allowing for greater infiltration and putting less strain on retention basins.

34 ✓

Furthermore, by decreasing the slope length, less sediment will erode from the slopes, and much less sediment will accumulate in the retention structures. The runoff water quality will be improved prior to the water entering retention structures, reducing the amount of potential accumulated contaminants, decreasing the load in the wastewater treatment plant, and possibly achieving water quality acceptable for direct discharge.

Vegetated waterways are channels protected by vegetation and designed to absorb runoff water energy without damage to the soil (260). Waterways are used to safely channel runoff from watersheds, terraces, diversion channels, and ponds. Thus, in a typical sludge landfill, runoff water from a sloping area would be intercepted by either a terrace or diversion

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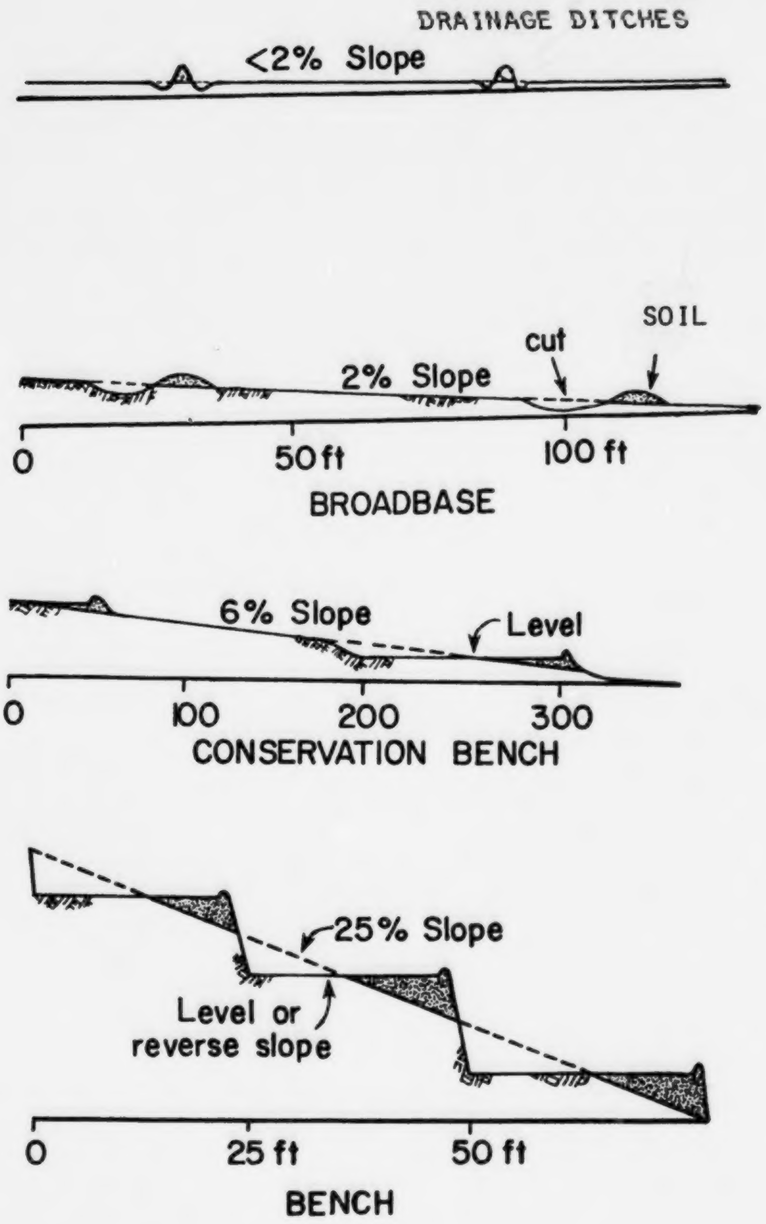
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CONSERVATION BENCH
25% Slope
Level or
reverse slope
0
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BENCH

Figure 34. Examples of general types of terraces from Schwab et al. (260).

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ditch and would flow to a vegetated waterway which would allow it to flow to a retention basin without causing erosion. Schwab et al. (260) details the design dimensions for terraces and grassed waterways.

MUD CONTROL

Mud is inevitable at a sludge landfill site during heavy rains or spring thaws. To minimize the effect of mud on operations, access road should be constructed of gravel, crushed stone, cinders, crushed concrete, or asphalt binders to make the roads more serviceable (28). To prevent transport vehicles from tracking mud into adjacent paved roads, a wash pad and hose should be located near the exit gate to clean mud from the vehicles.

VECTOR AND ANIMAL CONTROL

Vector and animal problems at sludge landfills can be prevented with proper soil cover practices. Other vectors such as flies and mosquitos are particularly important to control. Flies are attracted by the availability of food sources and breeding areas in the sludge (and refuse for codisposal operations), and mosquitos by the stagnant water bodies at the site that serve as hatcheries for eggs. Early or more frequent applications of cover material are necessary to deter burrowing animals and control the breeding of flies and mosquitos (269).

While daily cover application can eliminate open exposure of sludge wastes, burrowing can continue, and the resulting tunnels damage the structural integrity of the cover and may provide pathways for infiltration of surface water (281,282). This problem can be alleviated by selection of soil types that will not structurally support tunneling, e.g., sand or well-graded gravel (129). Furthermore, burrowing rodents may attack and damage a liner if it blocks their path to food or water. Rodents, particularly ground squirrels, have been known to eat PVC liner material (28).

Additionally, birds are attracted in large numbers by the availability of food. The problem can be minimized by frequent applications of cover material to discourage bird scavenging (269).

In the event vector populations become established or show a seasonal increase, extermination programs using insecticides and rodenticides may be necessary. Such programs must be carefully controlled and monitored so that they do not pose a health or safety hazard (28).

AESTHETICS CONTROL

To make a sludge landfill site as inoffensive and acceptable as possible, every attempt should be made to keep the site compatible with its surroundings. Visual barriers such as trees or berms should be used to hide landfilling operations from public view. The use of architectural effects at the receiving area, the planting of trees along the property line, and confining dumping to designated areas will assist in the development of a sound operation.

Soil cover should be applied to exposed sludges as frequently as possible. Disturbed areas should be revegetated for codisposal sites, blowing paper should be minimized during daily operations by containment fencing. All levees and terraces which are constructed as a means of water diversion or retention should be planted immediately on a permanent cover. Without a vegetative cover, such areas will erode quickly and require constant maintenance which will often be difficult to perform during wet periods when a critical need may occur.

NOISE CONTROL

Sources of noise at sludge landfills include operating equipment and haul vehicles. As noted in Section 4, not all sludge landfilling methods use the same number of operating equipment; therefore, potential noise impacts will vary correspondingly. The following techniques can be used to reduce operational noise (136).

- Schedule landfilling operations to keep average noise levels low, e.g., schedule the noisiest operation to coincide with times of highest ambient levels;
- Route transport vehicles through the least populated areas;
- Maintain speed limits to minimize noise from vehicles;
- Keep noisy equipment operations as far as possible from site boundaries; and
- Provide enclosures or sound shields for stationary items of equipment and barriers around particularly noisy areas on the site, or around the site.

PERSONNEL HEALTH AND SAFETY CONTROL

Personnel health at sludge landfill facilities can be endangered in the following ways:

- Exposure to sludge toxins or pathogens, both acute and chronic;
- Accidents while operating heavy equipment; and
- Fires or explosions.

Acute or chronic exposure to sludge may cause immediate sickness or long-term illness. Some WWTP sludges give off obnoxious odors during storage or applicaton phases of operations. A respirator is usually sufficient to eliminate most of the effects associated with breathing these gases. The threat of airborne pathogens can also be eliminated by respirators. If present, volatile carcinogens may be more difficult to protect against.

Probably the most common causes of personnel injury at land treatment facilities are operator errors with heavy equipment. By following standardized operating procedures that are laid out in personnel training sessions and safety manuals, these accidents can be largely avoided.

Fires or explosions are a potential threat from methane generated during sludge decomposition. This is particularly true for codisposal operations where dry refuse can act as a fuel for combustion. Cigarette smoking or sparks from vehicles and landfilling equipment may also ignite the gas.

In general, sludge landfill sites should be designed, constructed, and operated in a manner so as to protect the health and safety of personnel and users through compliance with relevant provisions of the Occupational Safety and Health Act of 1970 (OSHA--Public Law 91-596) and regulations promulgated thereafter. This agency has developed specific operational criteria for most situations in the work place and should be consulted to facilitate the development of safety training procedures and operation safety standards.

The main objective of implementing safety procedures is to maintain the health and welfare of facility personnel and site visitors. Additionally, safety measures contribute to lower costs through increased efficiency of operations and decreased equipment maintenance. In conjunction with the aforementioned OSHA provisions, the proposed EPA "Guidelines" for the landfill disposal of solid wastes (269) recommend the following safety measures.

- Safety manuals should be provided and employees instructed in application of its procedures;
- Safety devices such as roll over protective structures and seat belts should be provided on all equipment used to spread and compact sludges;
- Work areas and access roads should be well marked to avoid on-site vehicle mishaps;
- Cigarette smoking should be prohibited in the disposal area;
- Vehicles and landfill equipment should be equipped with spark arresters;
- Personal safety devices such as hard hats, gloves, safety glasses, and footwear;
- Washing facilities should be located on or near the disposal site for use in case of bodily contact with sludge;
- Communication equipment should be available on-site for emergency situations;
- A source of water should be provided on-site for fire and dust control; and
- Following closure of a completed landfill, a long term maintenance program should be initiated.

SUMMARY

This section has presented a survey of the available technology which may be used to control environmental/public health impacts connected with sludge landfilling. A major portion of the discussion centered on leachate and ground-water control techniques since ground and surface water contamination is a major potential environmental/public health risk associated with sludge landfilling, as determined in the previous sections.

Leachate and ground-water control techniques may be separated into two areas: input control and output control. Input control measures obviate the input of moisture to the landfills, moisture resulting from infiltration from rainfall or surface water runoff, and from ground water intrusion. Input control technology includes artifical and natural liners, slurry trenches, grout curtains, and cutoff walls. Output control concerns the prevention of landfill leachates from entering ground-water resources, or interception and collection of contaminated ground water. Output control technologies can include those

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common to input control (i.e., liners, slurry-trenches, grout curtains, and cutoff walls), plus bottom sealers, drains, and well point systems. To assure the success of a leachate/groundwater control measure, ground-water monitoring is recommended.

It is important to note that no single leachate or groundwater control technique is effective for all landfill situations. Often, a combination of techniques is necessary to prevent water quality impairment. The selection of an appropriate technique(s) is dependent on site-specific conditions.

Besides leachate problems, air emission, erosion, mud, vector and animal, aesthetics, noise, and personnel health and safety problems may also be controlled through techniques described in this section. Because of the survey nature of this section, a review of referenced material may be needed where more depth is desired.

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SECTION 8

MANAGEMENT OPTIONS

The development of management options is based upon the evaluation of current WWTP sludge landfilling practices, the type of WWTP sludges placed in the fill, the related environmental/health impacts and other special constraints of WWTP sludge landfilling. Appropriate control technology will be suggested according to the magnitude of the potential environmental impacts anticipated from WWTP sludge landfilling. Operational considerations, including a review of landfilling conditions which merit dewatering and stabilization, are discussed. Special constraints of WWTP sludge landfilling will be identified.

SELECTION OF LANDFILLING METHOD

While landfilling of WWTP sludge can be accomplished without significant degradation of the environment, improper management can lead to its decline. For a given sludge(s) and site condition and provided appropriate design criteria, an optimal disposal alternative can be selected which will maintain public health and environmental stability. The EPA has established guidelines for such a selection, and these are listed in Tables 46 and 47.

As shown by these guidelines, the important features governing the selection of an appropriate sludge landfill are:

- Sludge solids content;
- Sludge characteristics (stabilized or unstabilized);
- Hydrogeology (deep or shallow ground water or bedrock);
- Ground slope;
- Landfill cover thickness; and
- Application rate.

Since landfilling of WWPT sludge is constrained by environmental impacts, public health impacts, costs, and the availability of land, the selection process must estimate the

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TABLE 46. SLUDGE AND SITE CONDITIONS FOR CURRENT LANDFILLING PRACTICES (28)

Method	Sludge solids content (percent)	Sludge characteristics	Hydrogeology	Ground slope
Narrow trench	15–28	Unstabilized or stabilized	Deep groundwater and bedrock	<20 percent
Wide trench	≥20	Unstabilized or stabilized	Deep groundwater and bedrock	<10 percent
Area fill mound	≥20	Stabilized	Shallow groundwater or bedrock	Suitable for steep terrain as long as level area is prepared for mounding
Area fill layer	≥15	Unstabilized or stabilized	Shallow groundwater or bedrock	Suitable for medium slopes but level ground preferred
Diked containment	≥20	Stabilized	Shallow groundwater or bedrock	Suitable for steep terrain as long as a level area is prepared inside dikes
Sludge/refuse mixture	≥3	Unstabilized or stabilized	Deep or shallow groundwater or bedrock	<30 percent
Sludge/soil mixture	≥20	Stabilized	Deep or shallow groundwater or bedrock	<5 percent

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TABLE 47. DESIGN CRITERIA FOR CURRENT LANDFILLING PRACTICES (28)

Method	Sludge solids content (percent)	Trench width (ft)	Bulking re-quired	Bulking agent	Bulking ratio	Cover re-quired	Method of cover application	Cover thickness (ft) In-terim	Cover thickness (ft) Final	Im-ported soil required	Sludge application rate (in actual fill areas)	Equipment
Narrow trench	15–20	2–3	No	—	—	Yes	Land-based equipment	—	2–3	No	1,200–5,600	Backhoe with loader, excavator, trenching machine
	20–28	3–10	No	—		Yes	Land-based equipment	—	3–4			
Wide trench	20–28	>10	No	—	—	Yes	Land-based equipment	—	3–4	No	3,200–14,500	Tractor loader, dragline, scraper, track dozer
	≥28	>10	No	—		Yes	Sludge-based equipment	—	4–5			
Area fill mound	≥20	—	Yes	Soil	0.5–2 soil:1 sludge	Yes	Sludge-based equipment	3	1	Yes	3,000–14,000	Track loader, backhoe with loader, track dozer
Area fill layer	≥15	—	Yes	Soil	0.25–1 soil:1 sludge	Yes	Sludge-based equipment	0.5–1	1	Yes	2,000–9,000	Track dozer, grader, track loader
Diked containment	20–28	—	No[b]	Soil	0.25–0.5 soil:1 sludge	Yes	Land-based equipment	1–2	3–4	Yes	4,800–15,000	Dragline, track dozer, scraper
	≥28	—	No[b]	Soil		Yes	Sludge-based equipment	2–3	4–5			
Sludge/refuse mixture	≥3	—	Yes	Refuse	4–7 tons refuse:1 wet ton sludge	Yes	Sludge-based equipment	0.5–1	2	No	500–4,200	Track dozer, track loader
Sludge/soil mixture	≥20	—	Yes	Soil	1 soil:1 sludge	No	—	—	—	No	1,600	Tractor with disc, grader, track dozer, track loader

[a] Volume basis unless otherwise noted
[b] But sometimes used

1 ft = 0.305 m
1 yd^3 = 0.765 m^3
1 acre = 0.405 ha

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potential magnitude of each of these factors with regard to each landfilling alternative. Table 27 (Section 4 "Current Landfilling Practices") shows the results of these efforts.

As indicated in Table 27, the land required for each landfilling alternative shows that codisposal techniques, sludge only narrow trench, and sludge only layer fill methods are the most land intensive. Application rates for these alternatives are generally below 9000 yds^3/acre (28). Sludge only alternatives including wide trenches and area fill techniques are amenable to high residual application, e.g., >14,000 yds^3/acre.

Comparing potential environmental impacts of each of the landfilling alternatives is highly speculative, since impacts are largely governed by the quality of the sludge, site selection, and efficiency of operation. It cannot be assumed, for instance, that the potential environmental/public health impacts of sludge/refuse codisposal operations will be greater than conventional refuse landfills without accounting for the quality of the sludge. An unstabilized, liquid sludge admixed with refuse does pose greater environmental/public health risks than a conventional refuse landfill. A sterile, odorless, dewatered sludge cake admixed with refuse and engineered to prevent leachate production and/or migration does not pose greater risk. Again, the character of the sludge rather than landfilling method will define the environmental/public health risks of sludge landfilling.

Cost evaluation for each of the alternative landfilling methods in Table 27 are based upon scenarios developed by SCS Engineers using average design dimensions and average application rates (28) (Table 48). Among the costs considered are hauling, capital, operating, and total site costs. The cost curves presented in Figures 35 - 38 are updated to 1981 dollars based on information provided in the SCS Engineer's report (28).

Estimated hauling costs for WWTP sludge are given in Figure 35. The hauling costs reflect not only transportation costs, but also the cost of sludge loading and unloading facilities. Loading and unloading facilities were found to contribute more heavily to total hauling costs with decreasing quantities of sludge received at the site (28).

The following assumptions were made in order to produce the 1981 hauling cost curves:

1. The sludge was dewatered and had a solids content of approximately 20%. It was hauled by a 15 yd^3 (11.5m^3), 3-axle dump truck.

2. Hauling was performed 8 hrs per day, 7 days per week.

TABLE 48. COST SCENARIOS FOR ALTERNATIVE LANDFILLING METHODS (28).

Identification			Site Preparation				Sludge Bulking			Sludge Filling			Sludge Covering			Miscellaneous	
Scenario No.	Landfilling method	Sludge Solids Content (%)	Width (ft)	Depth (ft)	Length (ft)	Spacing (ft)	Bulking Performed	Bulking agent	Bulking ratio (bulking agent: sludge)[a]	Sludge depth per lift (ft)	No. of lifts	Sludge application rate (yd^3/acre)	Cover applied	Cover Thickness Interim (ft)	Cover Thickness Final (ft)	Imported soil required	Primary equipment
1	Narrow trench[a]	22	6	6	100	9	No	—	—	4	1	2,580	Yes	—	4	No	Backhoe with loader, track dozer, excavator
2	Wide trench[b]	32	60	8	600	30	No	—	—	4	1	4,100	Yes	—	5	No	Track loader, scraper, track dozer
3	Area fill mound[b]	30	—	—	—	—	Yes	Soil	1:1	6	2	9,680	Yes	3	1	Yes	Track loader, backhoe, track dozer, scraper, wheel loader
4	Area fill layer[b]	30	—	—	—	—	Yes	Soil	0.5:1	2	2	4,300	Yes	0.5	1	Yes	Track dozer, scraper, grader, wheel loader
5	Diked containment[a]	25	50	30	100	30	Yes	Soil	0.5:1	6	4	12,410	Yes	1	3	Yes	Dragline, track dozer, scraper
6,	Sludge/refuse[b] mixture	20	—	—	—	—	Yes	Refuse	7 tons:1 wet ton	6	3	2,520	Yes	0.5	2	No	Track dozer, truck loader
7	Sludge/soil[b] mixture	20	—	—	—	—	Yes	Soil	1:1	1	1	1,600	No	—	—	No	Tractor with disc, grader, track loader

1 ft = 0.305 m
1 yd^3 = 0.765 m^3
1 acre = 0.405 ha

[a] Land-based

[b] Sludge-based

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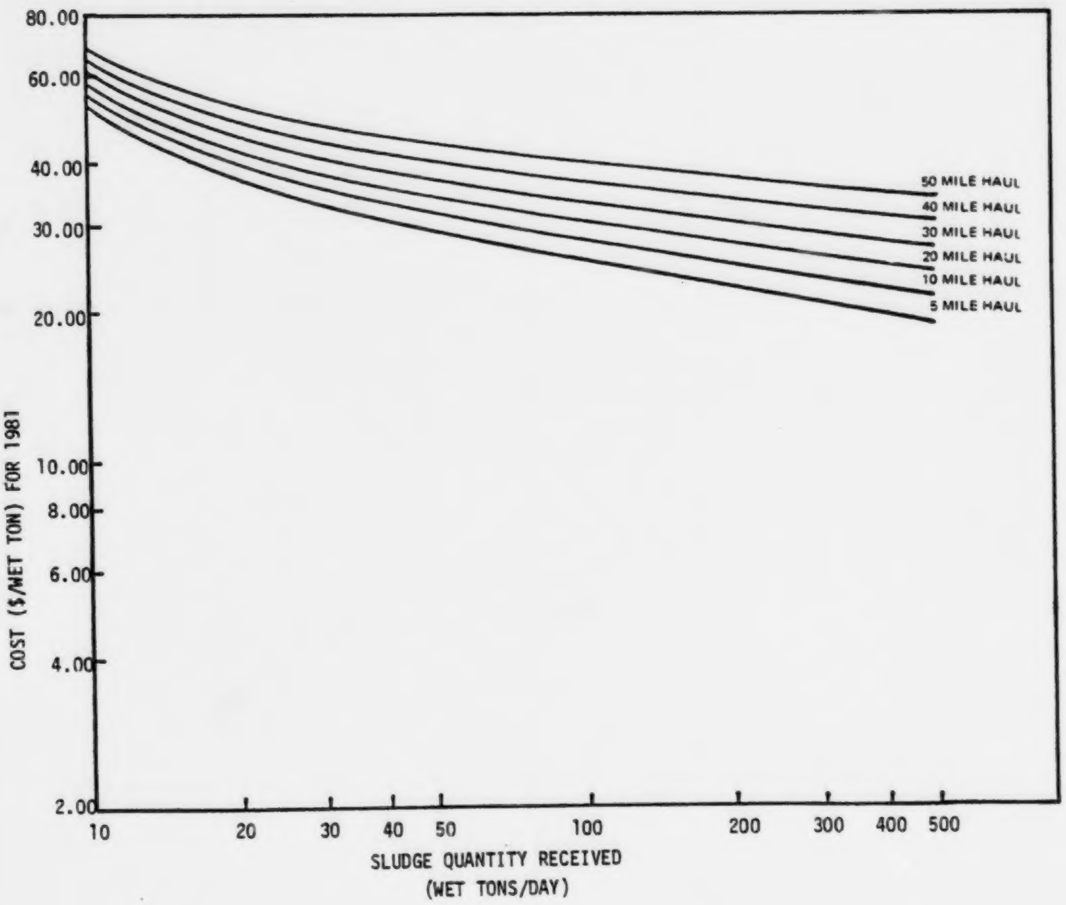

Figure 35. Estimated hauling costs (modified from Reference 28).

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Fig ___ Estimated hauling costs
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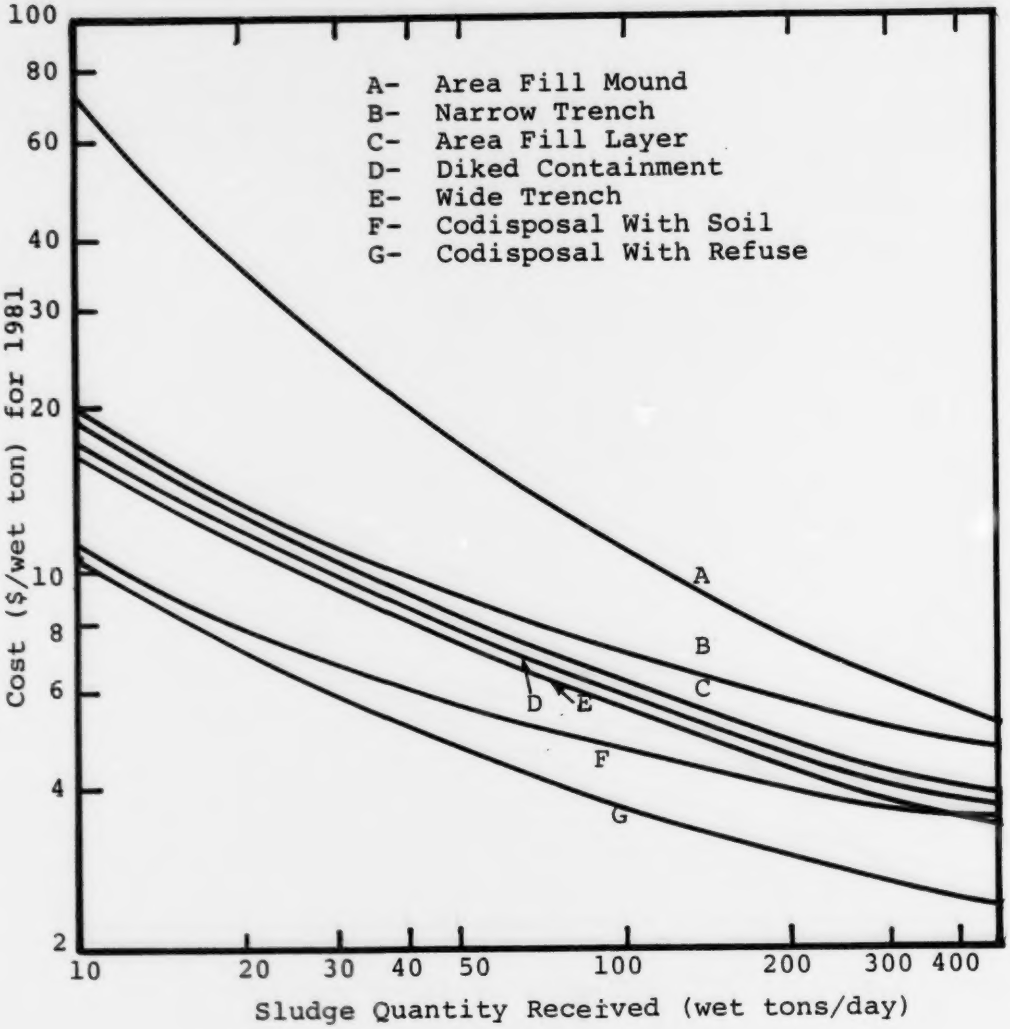

Figure 36. Estimated site operating costs for sludge landfilling. (Modified from Reference 28)

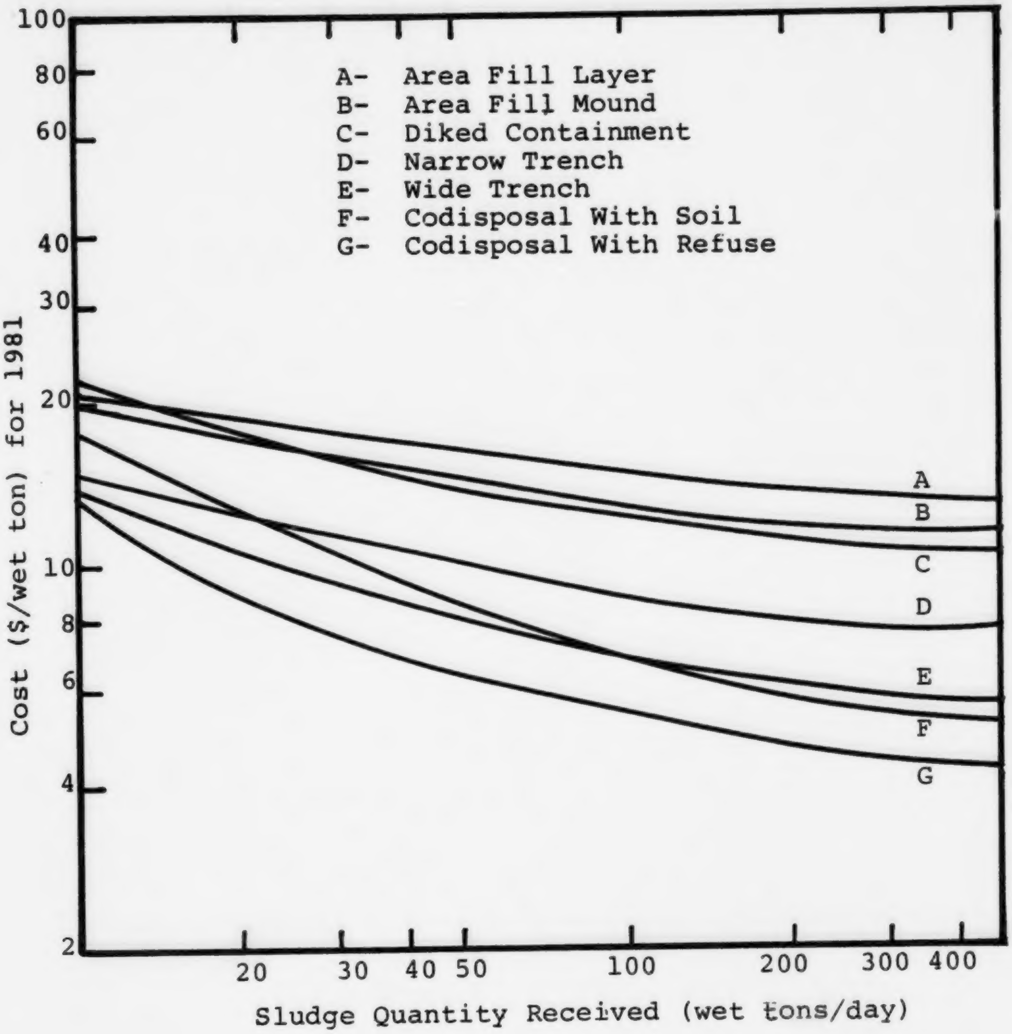

Figure 37. Estimated captital costs for sludge landfilling. (Modified from Reference 28)

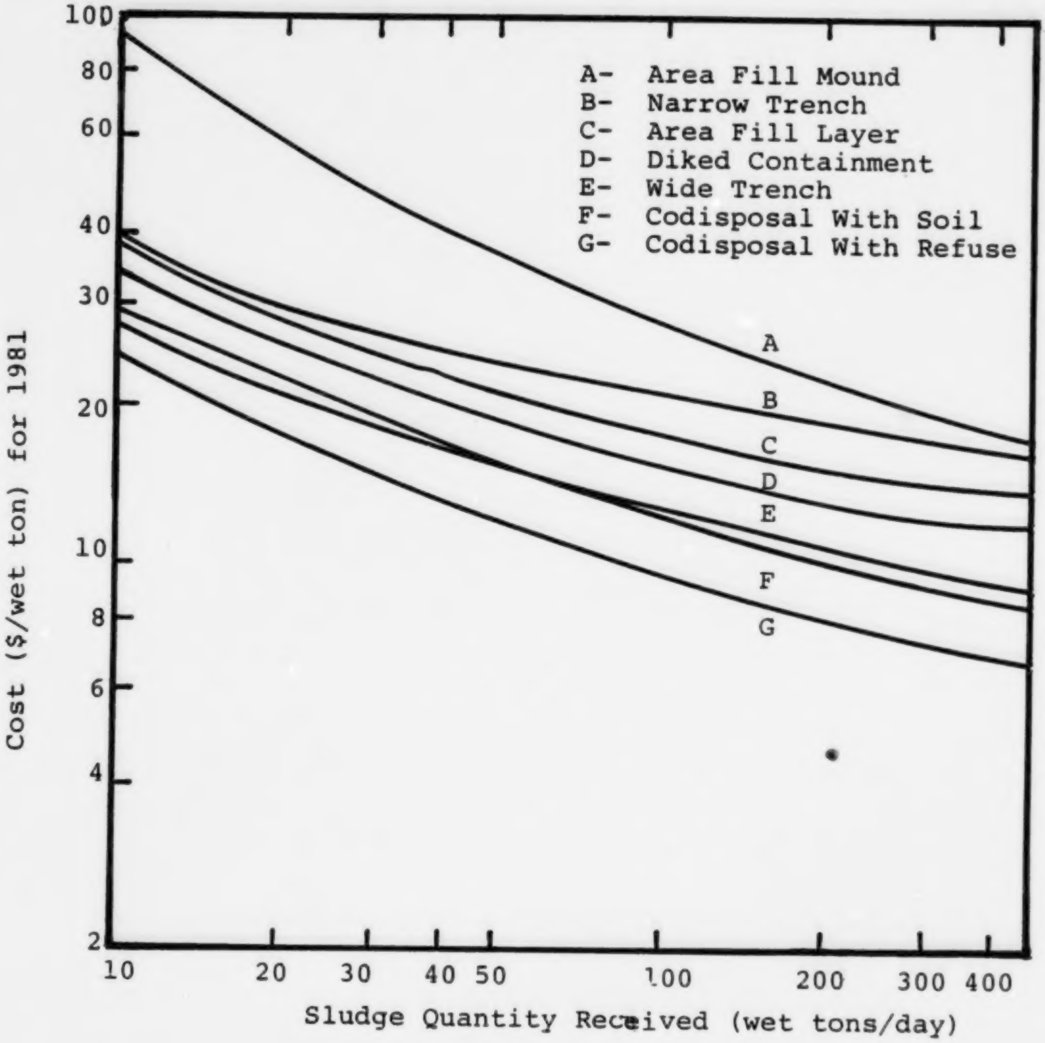

Figure 38. Estimated total site costs for sludge landfilling (combined capital and operating costs). (modified from Reference 28)

3. Fuel cost was $1.30 per gal.

4. Labor (primarily truck driving) costs were $14.00 per hr including fringe benefits.

5. Overhead and administrative costs were 25% of the operating costs.

6. Capital costs were annualized. A rate of 15% over 6 years was used for the trucks with a salvage value of 15%. A rate of 15% over 25 years was used for loading and unloading facilities with no salvage value.

Figure 36, capital costs for sludge landfilling, included the following capital items (28):

1. Land.

2. Site preparation (clearing and grubbing, surface water control ditches and ponds, monitoring walls, soil stockpiles, roads and facilities).

3. Equipment purchase.

4. Engineering.

Capital costs were analyzed at 15% over 5 years (the assumed life of the site) and divided by the sludge quantity delivered to the site in one year.

Operating costs are summarized in Figure 37. Operating cost items included (28):

1. Labor

2. Equipment fuel, maintenance and parts

3. Utilities

4. Laboratory analysis of water samples

5. Supplies and materials

6. Miscellaneous.

The original assumptions in developing these cost curves (28) were updated to reflect 1981 costs. These assumptions include:

1. Life of the landfill site was 5 years.

2. Land cost was $4,000 per acre.

3. Actual fill areas (including inter-trench spaces) consumed 50% of the total site area.

4. Engineering was 6% of the total capital costs.

5. Operating labor cost $14.00 per hour including fringe, overhead, and administration.

Based on the cost diagrams presented, a prioritized list of landfilling methods based on total costs with lowest costs first can be developed as follows:

1. Codisposal with sludge/refuse mixture
2. Wide trench (see Figure 38)
3. Codisposal with sludge/soil mixture (see Figure 38)
4. Narrow trench
5. Diked containment
6. Area fill layer
7. Area fill mound.

As described in the Process Design Manual for Municipal Sludge Landfills (28):

"Codisposal and wide trench methods tend to be the most economical landfilling methods. Codisposal operations tend to be larger and benefit from the economies of scale. In addition, the availability of "free" bulking material in the form of refuse reduces labor costs. Wide trenches have high application rates and are land and labor efficient. It should be noted however, that the relatively high solids content required for effective utilization of wide trenches will increase the cost of sludge handling at the treatment plant."

"Narrow trenches have relatively higher labor requirements and are land intensive, contributing to high capital and operating costs. Area fill mounds and layers are labor and equipment intensive."

"Diked containment requires a relatively large operation before it becomes a cost-effective means of landfilling. This is a result of high initial labor and equipment requirements. Once established, however, diked containments are efficient in terms of operation and land use."

Reclamation of a sludge landfill site is an environmental concern which is related to landfilling methods, though the properties of sludge and sludge/refuse mixtures are also relevant. The supportive strength associated with a sludge landfill is a function of its age and depth. Older, shallow, land intensive landfills are more amenable to supporting structures than younger, deeper landfills. Sludge landfill gases can be expected to vent for many years, representing a hazard to structures built on or near the site. The sludge-only narrow trenching method may be most advantageous to future land use because of its land intensive, shallow nature.

Reclaimed sludge landfills may also be used for recreation purposes, such as parks or botanical gardens. Investigations should first assure that harmful gases will not present a hazard in such areas, and that wildlife will not contact disease by foraging in such areas.

TYPES OF SLUDGES

Documented management options for WWTP sludge landfilling practices often recognize the types of the sludges destined for landfilling as a principle design constraint. Variables which affect the suitability of sludge landfilling will be discussed in this section, based on the following characters of WWTP sludges:

- Sludge solids content (or moisture content);
- Odor and vector problems;
- Operational difficulties;
- Leachate generation; and
- Methane production.

Where information is non-existent or incomplete, scientific judgement will be applied in the discussion.

Sludge Solids Content

The solids content of the sludges is a critical factor governing the suitability of the sludges for landfilling. Sludges of lower solids content (higher moisture content) are capable of producing greater volumes of leachate than sludges of higher solids content. As shown in Table 47, sludge solids content less than 3% is not suitable for sludge/refuse codisposal. For sludge-only landfilling methods, the minimum requirement for sludge solids content is usually 15 to 20%, depending on types of disposal methods used (Table 47).

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One of the advantages of sludge/refuse codisposal landfills is the ability of refuse to retain sludge moisture, thereby delaying or possibly preventing the production of leachate. However, surcharge loads produced by increasing landfill depth will limit the ability of refuse to retain sludge moisture, as will the effects of refuse decomposition. The Los Angeles County Sanitation District (37) developed working curves defining the maximum non-leaching sludge/refuse ratios as a function of sludge solids content and landfill depth, and is shown in Figure 39. The effects of rainfall will decrease the available absorptive capacity of refuse.

Odor, Vector and Operational Problems

Table 49 identifies the relative odor and vector problems of various WWTP sludges (8). Strong odors are normally encountered for unstabilized sludges of less than 30% solids content (8). Nuisance odors which develop after sludge is landfilled may be attributed to re-wetting of the buried sludge. Table 50 compares the potential odor problems between sludge-only and codisposal landfilling for different types of WWTP sludge (8). The same table also lists the suitability of landfilling in terms of operational problems.

Table 49 also presents the potential of WWTP sludge for vector attraction. Flies are by far the most numerous insect vector associated with landfilled sludge (39) - breeding and foraging in the decaying sludge with some species feeding on fungus growth (283). Flies are usually not associated with well-digested dewatered sludges, though it has been observed that they forage in solid waste wetted with sludge (39). Based on fly emergence studies conducted by Stone, the following speculative conclusions were drawn (39):

1. Six to eight inches of sand as soil cover will reduce, but not eliminate, fly emergence.

2. The cover soil available at the site (coarse to fine sand) is a rather poor barrier. During the peak fly season, emergence occurred despite six to eight inches of compacted soil.

3. Climatic conditions affect fly emergence by affecting the number of existing flies (i.e., fly seasons). Soil cover which may seem ineffective in August may be effective in October due to the smaller number of flies in October.

4. Sewage sludge admixed with solid waste has no detectable influence on fly propagation and emergence.

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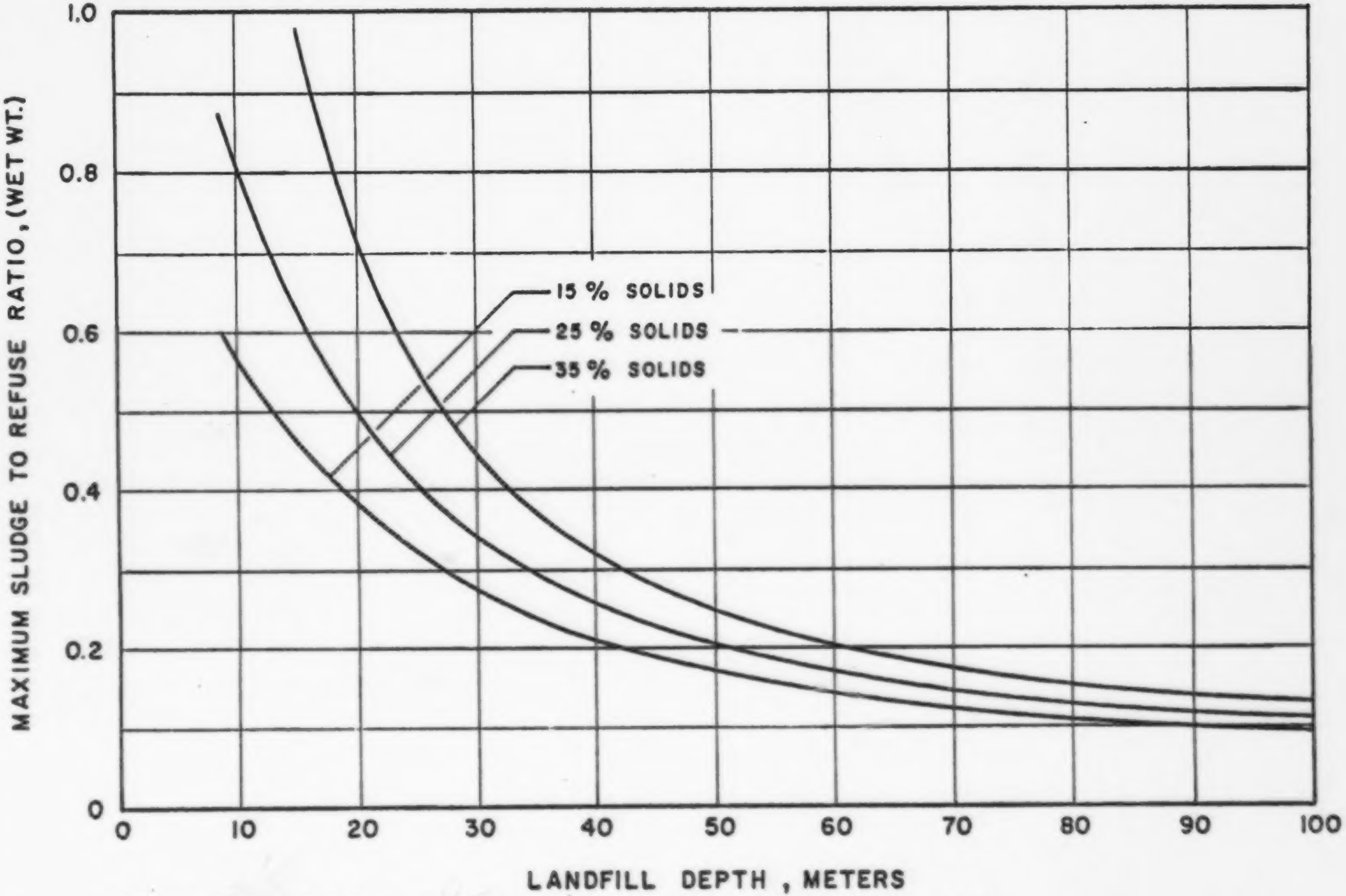

Figure 39. Maximum non-leaching sludge/refuse ratio (37).

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TABLE 49. CHARACTERISTICS OF WWTP SLUDGES PERTINENT TO LANDFILLING

Type of Sludge	Range of Solids Content (%)	Odor	Vector Attraction[†]	Pathogens
Liquid - unstabilized				
Gravity thickened primary (p), secondary (s), combined (c)* sludges without chemicals	2 - 10	strong (p,c) mild (s)	yes	bacteria (bac), viruses (vir), protozoa (pro), helminths (hel)[#] fungi (fun)[§]
Gravity thickened primary, secondary, or combined sludges with chemicals	3 - 12	strong (p,c) mild (s)	yes	bac, vir, pro, hel, fun
Flotation thickened secondary or combined sludges without chemicals	4.5 - 8.6	strong (p,c) mild (s)	yes	bac, vir, pro, hel, fun
Flotation thickened secondary or combined sludges with chemicals	4.0 - 7.3	strong (p,c) mild (s)	yes	bac, vir, pro, hel, fun
Liquid - stabilized				
Thickened anaerobically digested primary or combined sludges	2.0 - 10	mild	yes	bac, vir, hel, fun
Thickened aerobically digested primary or combined sludges	1 - 3	strong	yes	bac, vir, hel, fun
Thickened lime stabilized ($pH \geq 11.5$) primary or combined sludges	10 - 12	absent	no	hel, fun
Thickened chlorine stabilized primary or combined sludges	2 - 10	weak	no	hel, fun
Thickened heat stabilized (70°C, 30 min) primary or combined sludges	7 - 15	strong	yes	fun
Thickened irradiated (400 kilorads) primary or combined sludges	2 - 5	strong	no	fun
Dewatered - unstabilized				
Vacuum filtered thermally conditioned[**] primary or combined sludges	35 - 50	mild	yes	fun
Vacuum filtered lime conditioned[‡] primary, secondary, or combined sludges	18 - 35	mild	no	bac, vir, pro, hel, fun
Centrifuged primary, secondary, or combined sludges	8 - 22	strong	yes	bac, vir, pro, hel, fun
Centrifuged polymer conditioned primary, secondary, or combined sludges	8 - 36	strong	yes	bac, vir, pro, hel, fun
Dewatered - stabilized				
Drying bed, anaerobically digested primary or combined sludges	10 - >35	absent	no	hel, fun
Drying bed, aerobically digested primary or combined sludges	10 - >35	absent	yes	hel, fun
Drying bed, anaerobically digested and lime stabilized ($pH > 11.5$) primary or combined sludges	10 - >35	absent	no	hel, fun
Vacuum filtered or centrifuged, anaerobically digested primary or combined sludges	12 - 18	weak	no	bac, vir, hel, fun
Vacuum filtered or centrifuged, anaerobically digested and lime[‡] or polymer conditioned primary or combined sludges	18 - 33	weak	no	bac, vir, hel, fun
Vacuum filtered, aerobically digested primary or combined sludges	15 - 20	mild	yes	bac, vir, hel, fun
Centrifuged, heat treated (70°C, 30 min) anaerobically digested primary or combined sludges	18 - 40	weak	no	fun
Lagooned, anaerobically digested primary or combined sludges	20 - 40	weak	no	hel, fun
Pressure filtered, anaerobically digested, and lime conditioned[‡] primary or combined sludges	18 - 36	weak	no	bac, vir, hel, fun
Heat dried				
Heat dried, anaerobically digested sludge	80 - 95	absent	no	fun
High temperature processed				
Incinerated dewatered primary or combined sludges	>95	absent	no	bac, hel, fun
Wet air oxidized primary or combined sludges	2 - 10	absent	no	bac, hel, fun
Special residuals				
Screenings	6 - 23	strong	yes	bac, vir, pro, hel, fun
Grit (unwashed)	35 - 87	strong	yes	bac, vir, pro, hel, fun
Grit (washed and dewatered)	50 - 87	mild	mod.	bac, vir, pro, hel, fun
Skimmings (excl. digester skimmings)	6 - 64	strong	yes	bac, vir, pro, hel, fun
Skimmings - digester	6 - 50	strong	yes	bac, vir, hel, fun

[*] primary plus secondary sludge (or preprocessed secondary)

[†] the potential for vectors (particularly flies) to be attracted to putrefactive sludge

[#] including nematodes (roundworms), and cestodes (tapeworms)

[§] fungi are only numerous in sludge when given the opportunity to grow during treatment or storage processes

[**] thermal conditioning can function as a stabilization process since rendering sludge free of pathogens

[‡] $pH < 11.5$

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TABLE 50. SUITABILITY OF WWTP RESIDUALS FOR LANDFILLING ACCORDING TO POTENTIAL ODOR AND OPERATIONAL PROBLEMS (8)

Type of Sludge	Sludge only landfilling		Codisposal landfilling	
	Suitability	Reason	Suitability	Reason
Liquid - unstabilized				
Gravity thickened primary, WAS and primary, and WAS	NS	OD, OP	NS	OD, OP
Flotation thickened primary and WAS, and WAS without chemicals	NS	OD, OP	NS	OD, OP
Flotation thickened WAS with chemicals	NS	OP	NS	OD, OP
Thermal conditioned primary or WAS	NS	OD, OP	MS	OD, OP
Liquid - stabilized				
Thickened anaerobic digested primary and primary, and WAS	NS	OP	MS	OP
Thickened aerobic digested primary and primary, and WAS	NS	OP	MS	OP
Thickened lime stabilized primary and primary, and WAS	NS	OP	MS	OP
Dewatered - unstabilized				
Vacuum filtered, lime conditioned primary	S	-	S	-
Dewatered - stabilized				
Drying bed digested and lime stabilized	S	-	S	-
Vacuum filtered, lime conditioned digested	S	-	S	-
Pressure filtered, lime conditioned digested	S	-	S	-
Centrifuged, digested and lime conditioned digested	S	-	S	-
Heat dried				
Heat dried digested	S	-	S	-
High temperature processed				
Incinerated dewatered primary and primary, and WAS	S	-	S	-
Wet-air oxidized primary and primary, and WAS	NS	OD, OP	MS	OD, OP

WAS = Waste-activated sludge, NS = Not suitable, MS = Marginally suitable, S = Suitable, OD = Odor problems, OP = Operational problems

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Finally, Table 49 lists the various classes of pathogens associated with WWTP sludges. The sludge pathogens are key parameters in estimating the public health risks posed by sludge landfills. The degree of hazard presented by pathogenic organisms which may be present in a landfill depends on three basic factors. They are (157):

- The initial concentration and nature of pathogens in the waste;
- The extent of survival of pathogens within the fill; and
- The possibility of transmission of pathogens from the fill into the environment.

Though raw primary sludges may be heavily contaminated by pathogens, wastewater and sludge treatment processes can significantly diminish the classes and concentrations of pathogens. Table 49 shows that dewatering can also assist in removing pathogens from sludge prior to landfilling. Note that fungi are a component of literally every sludge listed in Table 49. Fungi are not normally a component of fresh sludge or ash received at a landfill site, but fungi spores are ubiquitous in nature and may grow on suitable organic substrates such as sludge.

The extent of pathogen survival in WWTP sludge once landfilled needs further definition. Studies have shown that pathogenic organisms can be eliminated by pasteurization at 70°C for 20 minutes (59). Gotaas (284) and Golueke and Gotaas (285) among others have demonstrated that temperatures of 60°C held for one hour should kill all non-spore-bearing pathogens. The upper range of temperatures generally found in sanitary landfills with and without sewage sludge admixture is 45°C to 65°C. The higher end of a landfill temperature range in combination with increased time of exposure appears to be sufficient to destroy the majority of pathogens.

Leachate Generation

Table 51 summarizes the potential leachate contaminants for sludge-only and codisposal landfills based on results of the literature searches (refer to Section 5, Potential Environmental Impacts). Unstabilized sludges are judged to pose the greatest risks in terms of the range of potential leachate contaminants. Some stabilization processes such as chlorine oxidation, high lime treatment (pH >11.5), heat treatment, (70°C, 20 min), or irradiation (400 kilorads) can effectively reduce their pathogenic threat through leachates generation. Lime stabilization (pH >11.5) and lime conditioning in conjunction with dewatering (>25% solids) is believed to eliminate the threat of nitrate in sludge leachates. Heavy metals are considered a

TABLE 51. POTENTIAL LEACHATE CONTAMINANTS OF CONCERN

Type of sludge	Sludge-only landfills	Codisposal landfills
Liquid - unstabilized		
Gravity thickened primary (p), secondary (s), or combined (c)* sludges without chemicals	organics (org), heavy metals (hm), nitrate (nit), pathogens (path), total dissolved solids (TDS)	org, hm, nit, path, TDS
Gravity thickened primary, secondary, or combined sludges with chemicals	org, hm, nit, path, TDS	org, hm, nit, path, TDS
Flotation thickened secondary or combined sludges without chemicals	org, hm, nit, path, TDS	org, hm, nit, path, TDS
Flotation thickened secondary or combined sludges with chemicals	org, hm, nit, path, TDS	org, hm, nit, path, TDS
Liquid - stabilized		
Thickened anaerobically digested primary or combined sludges	hm, nit, path, TDS	hm, nit, path, TDS
Thickened aerobically digested primary or combined sludges	hm, nit, path, TDS	hm, nit, path, TDS
Thickened lime stabilized (pH $\geq$ 11.5) primary or combined sludges	org, TDS	org, hm, nit, TDS
Thickened chlorine stabilized primary or combined sludges	org, hm, nit, TDS	org, hm, nit, TDS
Thickened heat stabilized (70°C, 30 min) primary or combined sludges	org, hm, nit, TDS	org, hm, nit, TDS
Thickened irradiated (400 krads) primary or combined sludges	org, hm, nit, TDS	org, hm, nit, TDS
Dewatered - unstabilized		
Vacuum filtered thermally conditioned ** or combined sludges	org, hm, nit, path, TDS	org, hm, nit, path, TDS
Vacuum filtered lime conditioned ‡ primary, secondary, or combined sludges	org, hm, path, TDS	org, hm, nit, path, TDS
Centrifuged primary, secondary or combined sludges	org, hm, nit, path, TDS	org, hm, nit, path, TDS
Centrifuged polymer conditioned secondary or combined sludges	org, hm, nit, path, TDS	org, hm, nit, path, TDS
Dewatered - stabilized		
Drying bed, anaerobically digested primary or combined sludges	hm, path, TDS	hm, path, TDS
Drying bed, aerobically digested primary or combined sludges	hm, path, TDS	hm, path, TDS
Drying bed, anaerobically digested and lime stabilized (pH $>$ 11.5) primary or combined sludges.	hm, path, TDS	hm, path, TDS
Vacuum filtered or centrifuged, anaerobically digested primary or combined	hm, nit, path, TDS	hm, nit, path, TDS
Vacuum filtered or centrifuged, anaerobically digested and lime‡ or polymer conditioned primary or combined	hm, path, TDS	hm, path, TDS
Vacuum filtered, aerobically digested primary or combined sludges	hm, nit, path, TDS	hm, nit, path, TDS
Centrifuged, heat treated (70°C, 30 min), anaerobically digested primary or combined sludges	hm, nit, TDS	hm, nit, TDS
Lagooned, anaerobically digested primary or combined sludges	hm, TDS	hm, TDS
Pressure filtered, anaerobically digested and lime conditioned‡ primary or combined sludges	hm, path, TDS	hm, path, TDS
Heat dried		
Heat dried, anaerobically digested	hm, TDS	hm, TDS
High temperature processed		
Incinerated dewatered primary or combined sludges	hm, TDS	hm, TDS
Wet air oxidized primary or combined sludges	hm, TDS	hm, TDS
Special residuals		
Screenings	org, hm, path, TDS	org, hm, path, TDS
Grit (unwashed)	org, hm, path, TDS	org, hm, path, TDS
Grit (washed)	hm, path, TDS	hm, path, TDS
Skimmings (excl. digester skimmings)	org, path, TDS	org, path, TDS
Skimmings - digester	org, path, TDS	org, path, TDS

* primary plus secondary sludge (or preprocessed secondary)

** thermal conditioning can function as a stabilization process since rendering sludge free of pathogens

‡ pH $<$ 11.5

Table 51

potential component of nearly all leachates, with the exception of lime stabilized sludge and skimmings. However, lime stabilized sludges when disposed with refuse are amenable to a substantial drop in pH resulting from the buffering effects of carbon dioxide released with refuse decomposition. Dissolved solids (TDS) can be present in high concentrations in essentially all sludge and refuse leachates. When sludge-only and codisposal landfilling methods are compared, both methods show similar leachate contaminants produced (refer to Table 51). Though sludge-only and codisposal landfills may have leachates of similar composition, Section 5 shows that contaminant concentrations may vary.

Leachate volume is another factor which should be considered for WWTP sludge landfilling. Factors affecting landfill leachate generation include sources of leaching water, characteristics of WWPT sludges and refuse, landfill surface and underlying soil conditions, refuse/sludge mix ratio, and disposal methods (120). The types of sludges can effect leachate generation to a great extent due primarily to the high moisture content and low permeability[*] (or high specific resistance[†]).

As described in Section 5 (Potential Environmental Impacts) a considerable volume of leachate may be generated merely by settlement and compaction of the landfill. This leachate generation is largely a factor of the initial sludge moisture content.

Low permeability sludges can affect long term leachate generation. Sludges with a low permeability will retard or reduce the leachate flow rate from the fill; a more permeable residual may hasten leachate flow rate. Figure 40 qualitatively compares the leachate flow rate among various types of WWPT sludges, based upon measured resistance values (5). As indicated in Figure 40, the greatest quantity of leachate produced occurs when incinerator ash residues represent the fill material. Though no specific resistance values are available for WWTP incinerator residues, the granular and inorganic nature of the ash implies its high permeability relative to other sludges. Coagulated raw and digested sludges are less permeable than

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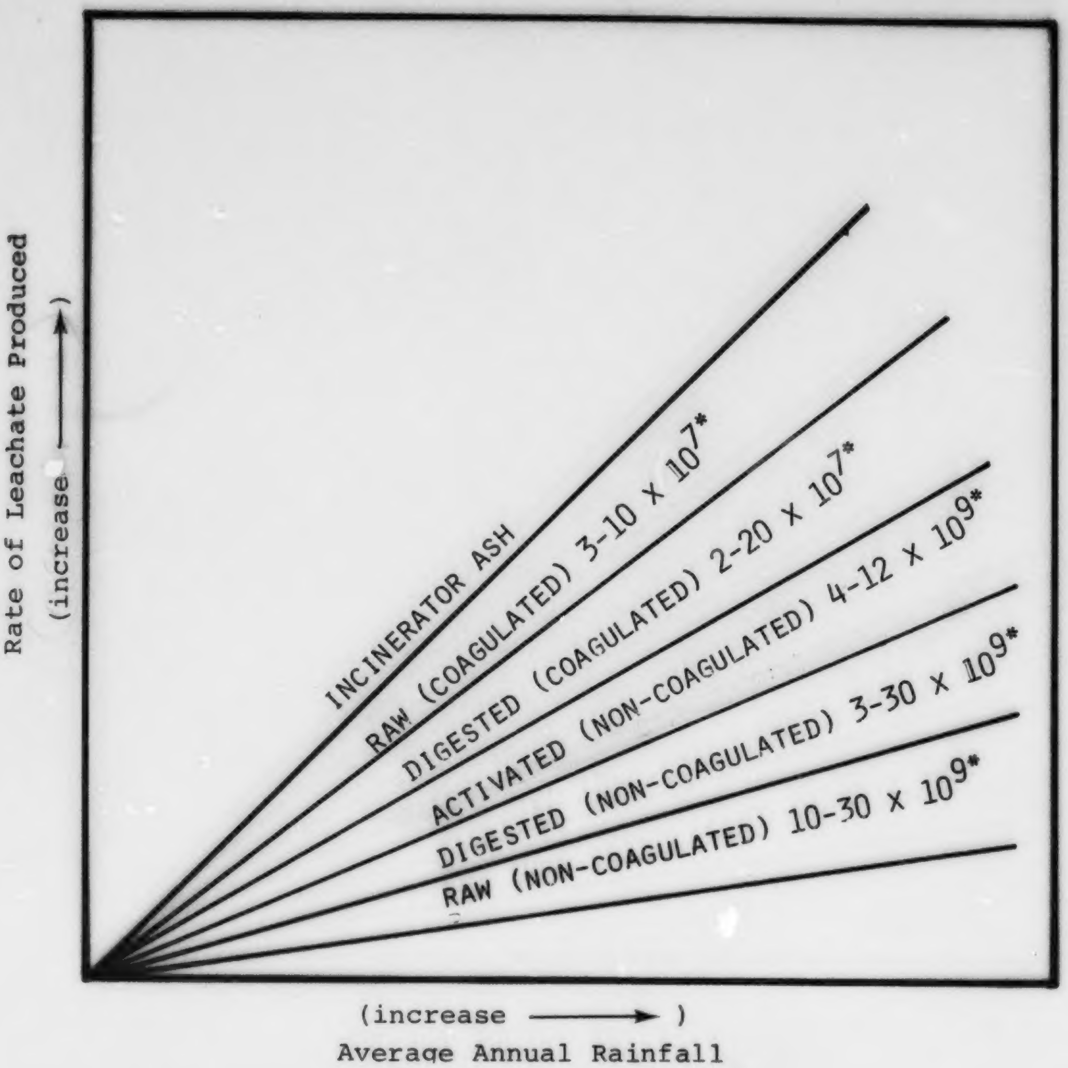
[*] Permeability, as expressed in standard soil mechanics terminology, is defined as the discharge velocity through a unit area under a unit hydraulic gradient. The units are commonly expressed as centimeters per second (cm/sec) or feet per year (ft/yr).

[†] Specific resistnace has been defined as the pressure required to produce a unit rate of flow through a cake having a unit weight of dry solids per unit area when the viscosity of the liquid is unity.



* specific resistance

Figure 40. Relative rate of leachate producible based on residual permeabilities.

incinerator residues, while non-coagulated raw, digested, and activated sludges are the least permeable type of sludge. The coagulated sludges, being agglomerates of smaller particles, allow fluids to pass through more readily than do the non-coagulated sludges. The water retention characteristics of the non-coagulated sludges are dominate factors in leachate production.

It is concluded that coagulation processes which tend to increase the dewaterability of WWTP sludges may present a disadvantage from the standpoint of leachate volume generation. Future research is necessary in order to quantify permeability values for various WWTP sludges to insure satisfactory estimates of leachate quantities and for defining the magnitude of the potential impact problems.

Methane Production

The potential volume of methane generated by anaerobic biodegradation at a landfill site is influenced by the WWTP sludge and/or municipal refuse organic content. Boswell and Neave (286) studied the specific gas production* of various residual components, as listed in Table 52. This research indicated that the breakdown of a residual with a high proportion of fats, oils, and greases can be expected to yield a greater quantity of gas per unit of solids destroyed. In general, the grease content of raw primary sludge can exceed 25% of the total solids; in biological sludges, it can be over 10% (refer to Section 3, Characteristics of WWTP Sludge). Scum and flotables are usually comprised of over 90% oil and grease.

TABLE 52. GAS PRODUCTION FOR SEVERAL COMPOUNDS IN WWTP RESIDUAL (286)

Material	Specific gas production,* cu ft per lb destroyed	CH_4 content, percent
Fats	18 - 23	62 - 72
Scum	14 - 16	70 - 75
Grease	17	68
Crude Fibers	13	45 - 50
Protein	12	73

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* expressed as cubic ft of gas per pound of volatile solids (vs) destroyed.

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The specific gas production from anaerobic digestion of raw primary WWTP sludges generally ranges between 12 to 17 ft^3 per pound of volatile solids destroyed. Of this gas, between 42.5 and 75% may represent methane (287). Complete microbial degradation of one pound of typical municipal refuse under optimal conditions yields approximately 4 ft^3 of methane (288, 289). Potential methane production is therefore greater for raw primary sludge landfills than for municipal refuse landfills.

Figure 41 presents the methane production potential for various WWTP sludges based on the average % volatile content of the sludges (290). Figure 41 shows the scum and raw primary sludges have the greatest potential for methane production. Municipal refuse alone is expected to generate more methane than any of the remaining sludges (see Figure 41). Judging from the total methane production in Figure 41, codisposal of scum or raw primary residuals with municipal refuse is likely to reduce methane production in comparison to that of sludge-alone landfilling. However, codisposal of municipal refuse with the remaining WWTP sludges is expected to enhance total methane production from the remaining sludges. It should be noted that these interpretations are speculative, and have not been substantiated by research.

The effects of adding municipal refuse to sewage sludge digesters upon methane production has received some attention. Hazeltine (291) investigated the digestion of garbage in anaerobic digesters and found that digestion of garbage produces acidic conditions not conducive to methane generation. However, ratios of 1.5 to 3 parts of garbage to 1 part sludge resulted in sufficeintly high pH values to re-establish methane production. Similarly, Golueke and McGauhey (290) noted that the pH decreased below the optimal 6.8 when the ratio of garbage (vegetable trimmings) to sewage sludge increased beyond 3 in 30 day digesters. Thus, available evidence indicates that sewage sludge addition to municipal refuse is advantageous in stimulating methane production.

AVAILABLE CONTROL TECHNOLOGY

To minimize environmental/health impacts, it is essential that the selection of a sludge landfill site be given special attention and that the site be properly designed, constructed, and operated. Often, these conditions will merit the implementation of pollution control technologies. This section will outline the control technologies for the minimization of the leachate as well as various environmental problems according to the following considerations:

- Conditions for implementation;

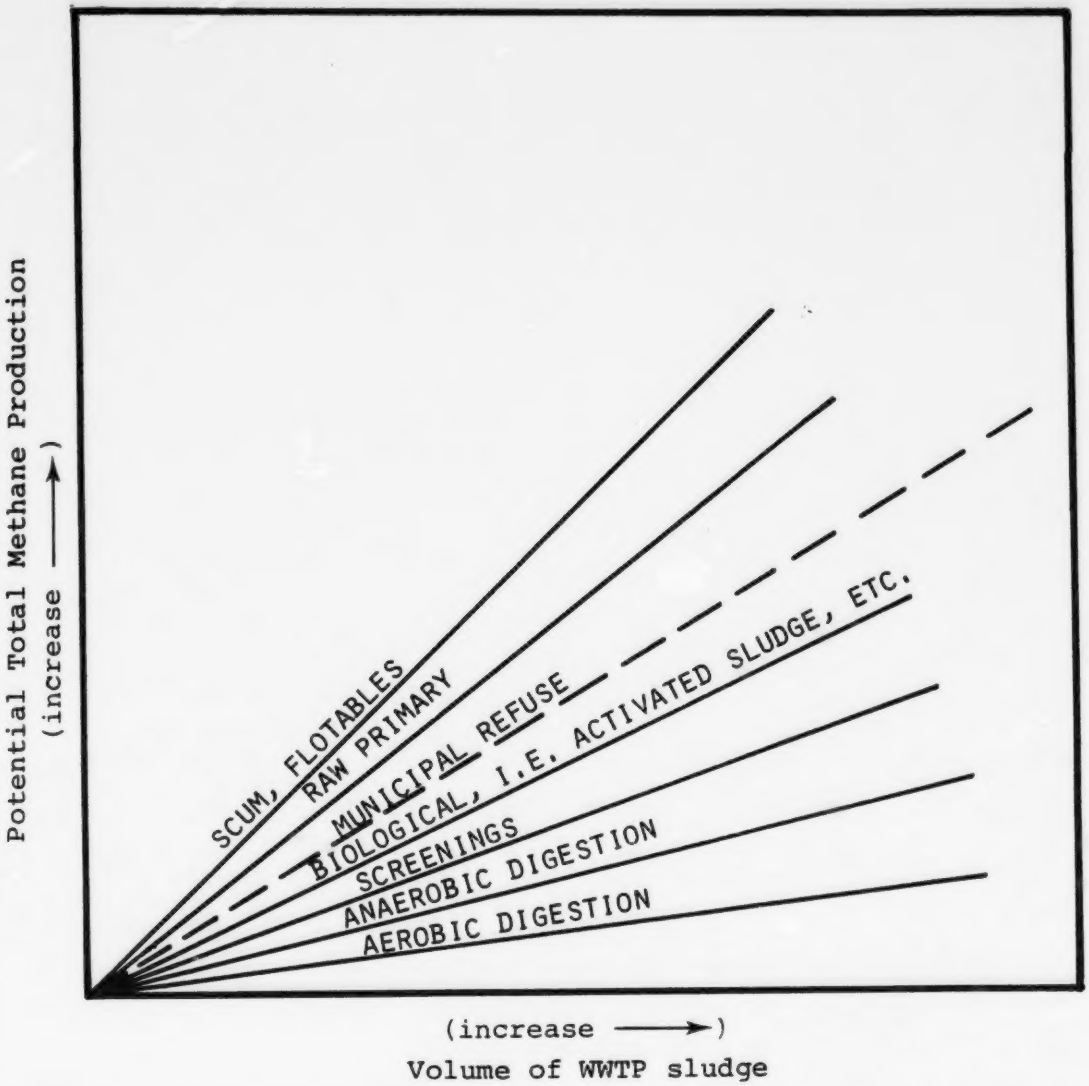

Figure 41. Qualitative comparison of the types of WWTP sludge and specific gas production.

- Control or treatment efficiencies; and
- Cost.

Leachate Control

In Section 5 it was established that WWTP sludges may have a negative impact upon receiving waters. To prevent or eliminate pollution created by landfill leachates, three control measures can be practiced: (1) prevention of leachate production, (2) recirculation of leachate back onto the landfill, and (3) collection and treatment of the leachate (262).

Leachate Generation Control--

In order to limit or prevent leachate volume generation two approaches are practiced. The first involves minimizing the moisture content of the WWTP sludges; the second, isolation of water contributions from surface and underlying ground waters. In this section, only the second approach will be discussed. The first approach will be discussed later under the heading of "Operational Considerations". Tables 53,54, and 55 summarize the available control methods and their estimated efficiencies and costs (120).

In terms of ground water/leachate isolation systems (Table 53), installation of artificial liners are feasible only prior to sludge or refuse placement. Other control methods may be utilized at completed landfill sites. The most efficient liners based on strength, durability, and relative permeability, are the ashpalt and Portland cement compositions. Liquid rubbers and synthetic polymeric membranes are amenable to tearing, punctures, and damage from organic solvents, and are considered less efficient (120). For existing sites, the slurry trench and grout curtain were rated as the most effective leachate isolation measures (120).

Costs associated with ground water/leachate isolation methods are difficult to estimate, due to variables such as materials availability, site conditions, energy costs for maintaining a control system, etc. Based on 1978 cost data, Table 53 presents the estimated costs for various control alternatives.

For surface water control systems, surface seals are optimal for retarding infiltration, but are the most expensive (Table 54). Contour grading and diversion ditches can achieve a high degree of surface water routing, and are less costly(120).

Revegation can reduce infiltration, and is cost-effective However, landfills continue to produce gases and soluble organic decomposition products which may damage vegetation (258, 292) for years after closure. Shallow rooted grasses are preferable for anaerobic landfill conditions. Special efforts should be

preferable

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TABLE 53. GROUND WATER CONTROL MEASURES (120)

Control Technique	Optimum Site Conditions	Limitations	Economics*	Percieved Effectiveness
Artificial Liner	Groundwater near to the refuse/soil interface. Underlying soils possess a moderately rapid to very rapid permeability 1.4×10^{-3} cm/sec to $>1.4 \times 10^{-2}$ cm/sec.	Requires installation prior to landfilling. Expected life not established. Rising groundwater may rupture the liner. May be damaged during landfilling activities Once installed, extremely difficult to repair	\$1.00 to \$5.00 per installed yd^2	Have been proven very effective in short-term usage, though long-term effectiveness sometimes questionable, depending on liner.
Bottom Sealer	Same as for artificial liner and when a detailed understanding of the soil is known.	Detailed understanding of soil properties are required. Only practical prior to landfilling.	\$1.20 to \$2.00 per installed yd^2	Effective in coarse-grained soils and gravel up to 90 m depth.
Slurry Trench	Near to surface groundwater and bedrock condition. Other conditions similar to those for an artificial liner.	Costs of shipping bentonite. Excavation difficult due to soil conditions. Deterioration of bentonite when exposed to high strength leachate may occur.	\$294 to \$495 per installed linear foot.	Effective ground-water control measure in rerouting shallow ground water flow.
Grout Curtain	Same as for an artificial liner as well as a near to surface bedrock condition	Considered effective in soils with permeabilities $>10^{-5}$ cm/sec. Costs may be prohibitive for large scale use. Difficult to assess the integrity of the seal.	\$142 to \$357 per installed m^3	A feasible solution for consolidated sand or cohesionless soils.
Sheet Piling Cutoff Wall	Same as for grout curtain.	Corrosion potential and problems with driving the sheet through rocky soils, ability to maintain integrity of the piling.	\$382 to \$562 per installed linear ft.	A maintenance-free means of preventing ground-water flow through a landfill.

* based on 1978 information

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TABLE 54. SURFACE WATER CONTROL (120)

Control Techniques	Optimum Site Conditions	Limitations	Economics†	Perceived Effectiveness
Contour Grading and Surface Water Diversion	Landfill stabilized; sufficient barrow area for soil excavation available nearby.	Available soil cover should be present. Differential settlement is extensive requiring large volumes of soil.	\$126,000 to \$242,000 for a 10 acre landfill.	An effective control measure used both during landfilling and once the fill has been stabilized.
Surface Sealing	Borrow material available; landfill has been stabilized and/or graded.	Suitable cover material may not be readily available. Gas venting may also be required.	\$140,000 to \$256,200 for a 10 acre site*	Effective if settlement is minimal and when used in conjunction with other control measures.
Revegetation	Stabilized fill and available cover soil (> 2 ft.). Minimum of settlement and gas control equipment available at the site.	Decomposition gases may be toxic to vegetation if not vented or controlled.	Approximately \$1000 per acre (240).	Provides a buffer to moisture entering the fill, and reduces erosion. Is most effective when employed in conjunction with several control measures.

* Based for a clay cap 6" thick; assumes earthmoving costs per acre at \$1,000.

† Based on 1978 information

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TABLE 55. LEACHATE PLUME CONTROL (120)

Control Technique	Optimum Site Conditions	Limitations	Economics*	Perceived Effectiveness
Drains	Near-to-surface ground water; soils which are easily excavated, consistent ground water level with little fluctuation.	Groundwater may be too low for effective use of drains. Soils may not be amenable to evcavation. Area required for drainage may be too large an area for practical drainage purposes.	$300-$800/acre	Effective when used in conjunction with other control approaches such as liners, well points, etc.
Well point system	Same as for drains	Usually effective for shallow dewatering purposes (≤10 m)	Capital cost, $1.33 per lineal ft. Maintenance and operational costs; $1.67 per lineal ft.	Effective when used to compliment another control system.
Deep well system	A greater quantity of water exists than a well point system may withdraw.	Capable of withdrawing approximately 40 vertical ft. of water in uniform sands.	Capital cost $18,000 to dewater 900 linear ft. Maintenance and operational costs $10,500/ year.	Effective in radically shifting the hydraulic gradient of a large body of water in a small area.

* based on 1978 information

directed to liming, fertilizing, amending, and mulching (129). Barriers, slots and vents should also be considered, if revegetation methods are practiced.

Collection Systems--

Leachate collection systems can be classified according to whether collection occurs solely by gravity (shallow drains) or by a system combining gravity and shallow or deep pumping wells. The shallow drain system, appropriate for residual trenching or area fill operations, represents significantly less capital and O & M costs as compared with the well system. The optimum site conditions, limitations, costs, and effectiveness for the collective system is shown in Table 56.

Leachate Recirculation--

Leachate recirculation involves the application of the collected leachate onto the top of the fill by surface irrigation. As a result, the moisture content of the solid waste is increased and presumably reaches an optimum necessary for anaerobic biological stabilization. The optimum site conditions, limitations, costs, and effectiveness for leachate reciruclation is shown in Table 56. Advantages of leachate recirculation include natural acceleration of landfill stabilization and absence of leachate treatment systems. Disadvantages include high capital and maintenance costs, the possible increase in leachate volume cumulation, and the need to carefully monitor the leachate application.

Leachate Treatment--

The most recent leachate treatment technology involves conventional biological or physical-chemical methods. Though these methods have been applied exclusively to refuse landfill leachates, they are presumably applicable to WWTP sludge leachates because of the generally similar nature of the two leachates.

The principal constraints of leachate treatment systems are (1) the inefficiency of proposed technologies, (2) leachate treatment state-of-the-art is still embryonic, and (3) costs (120). Treatment efficiencies are hampered primarily by high contaminant concentrations and the extremely variable character of leachate, even at the same landfill site. Neither conventional chemical treatment nor biological treatment alone are considered satisfactory in reducing the bulk of contaminants present.

The simplest and least expensive method of leachate treatment has been suggested by Boyle and Ham (293). Their findings indicate that sanitary landfill leachate can be added to domestic wastewater in an extended aeration activated sludge plant at a level of at least 5% by volume (leachate COD ≅ 10,000 mg/l) without seriously impairing effluent quality. At greater than 5% by volume, leachate additions resulted in substantial solids

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TABLE 56. LEACHATE RECIRCULATION AND COLLECTION TECHNIQUES (120)

Control Techniques	Optimum Site Conditions	Limitations	Economics*	Perceived Effectiveness
Leachate Recirculation				
Spray Irrigation	High evaporation rates for the site; site vegetation well established. Site contouring minimizes ponding runoff, etc.	Practical only in dry months; wet weather conditions minimizes effectiveness. Pumping equipment, collection wells and associated piping is required.	Capital $30,900 (solid set). Operational and maintenance costs $3,500/year.	Most effective in arid regions or during the summer months when treatment efficiency is the highest.
Overland Flow	Land availability with existing leachate collection, spray equipment, and ditches for recycle: existence of rooted grasses and slope conducive to natural gravity flow. Favorable soil properties and high evaporation/evapotranspiration rates desired.	Large area requirements; leachate collection and distribution system required conducive weather conditions required for optimum use.	NA†	Provides an effective treatment scheme when land is available and climatic conditions are favorable.
Subgrade Irrigation	Collection and leachate distribution system exists for the fill.	Elaborate piping and distribution system required	$500 to $3,000 per acre Operational and maintenance costs ≈ $1,500/year	Provides an effective landfill stabilizatin mechanism ; largely unaffected by climatic conditions. Treatment efficiency is less than for spray irrigation or overland flow.
Leachate Collection Systems				
Shallow Drains	Shallow bedrock condition; homogenous off-site soils	For most effective use, require installation prior to landfilling; difficult to repair once damaged.	$300 to $800 per acre	Represents an effective collection method when properly designed.
Shallow Well Point System	Near-to-surface groundwater conditions	Electrical costs will increase; continuous use of equipment necessary for optimum use	See Leachate Plume Control	See Leachate Plume Control

* based on 1978 information   † NA = not available

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production, increased oxygen uptake rates, and poorer mixed liquor separation. Chain and DeWalle (262) reported similar results for a maximum leachate inflow of 4% by volume. Disadvantages of the combined treatment are the required increase in size of the secondary clarifier, and the decrease of organic matter removal efficiencies in biological processes and activated carbon units.

On-site treatment systems offer another alternative for leachate treatment. Figure 42 portrays the COD removal efficiencies for raw leachates of various demonstrated treatment systems (120). Each process is subject to a number of design variables, which may in part account for the range of observed efficiencies. Among the methods studied, the trickling filter, the aerated lagoon, and anaerobic digestion processes are the most efficient treatment methods for raw leachates, with COD removal efficiencies reported as high as 99%. Activated carbon systems also reported high COD removal efficiency (≅ 90%) although raw leachate quickly exhausts the adsorption potential of activated carbon. Because of reduced efficiencies and cost considerations, carbon adsorption is not considered appropriate for treatment of raw leachate. The reverse osmosis process exhibits effective COD removal, though fouling of the membranes by suspended solids, colloidal material, and iron hydroxides, renders this alternative completely impractical. Coagulation and oxidation systems generally remove less than 40% of the raw leachate organics.

The COD removal efficiencies of the previously described processes following initial biological treatment are also shown in Figure 42. The performance of activated carbon and reverse osmosis is greatly improved under these circumstances. Anion exchange resins also allow substantial COD reductions (120). Oxidation, coagulation, and aerated lagoons provide comparatively small COD removal.

Substantial reductions in inorganic contaminants generally cannot be achieved when utilizing those processes as described previously. Research indicates that the anaerobic filter may be an exception (294). Figure 43 indicates those treatment alternatives and related removal efficiencies for ammonia, and various heavy metals (120). Air stripping and activated sludge show high reductions in ammonia concentrations, while lime coagulation appears to be the optimal alternative for heavy metal removal.

Table 45 summarizes recommended treatment processes for optimum leachate treatment. Hypothetical contaminant concentrations in raw leachate are compared to a discharge standard established by agencies of the State of Pennsylvania.* This data dictates an approximate removal efficiency required for each of the contaminants considered. From Figures 42 and 43,

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* From Steiner, _et_ _al_. (268).

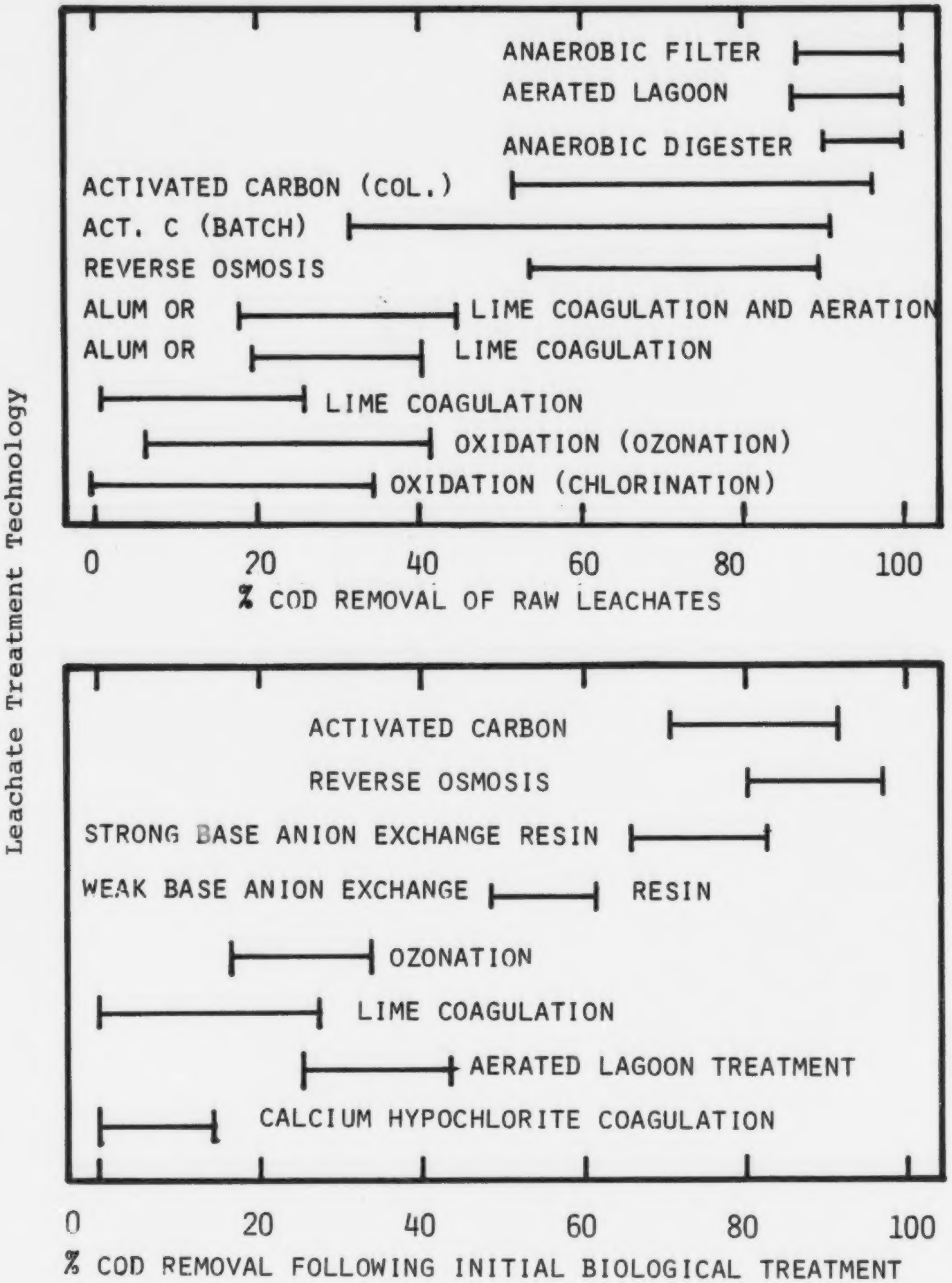
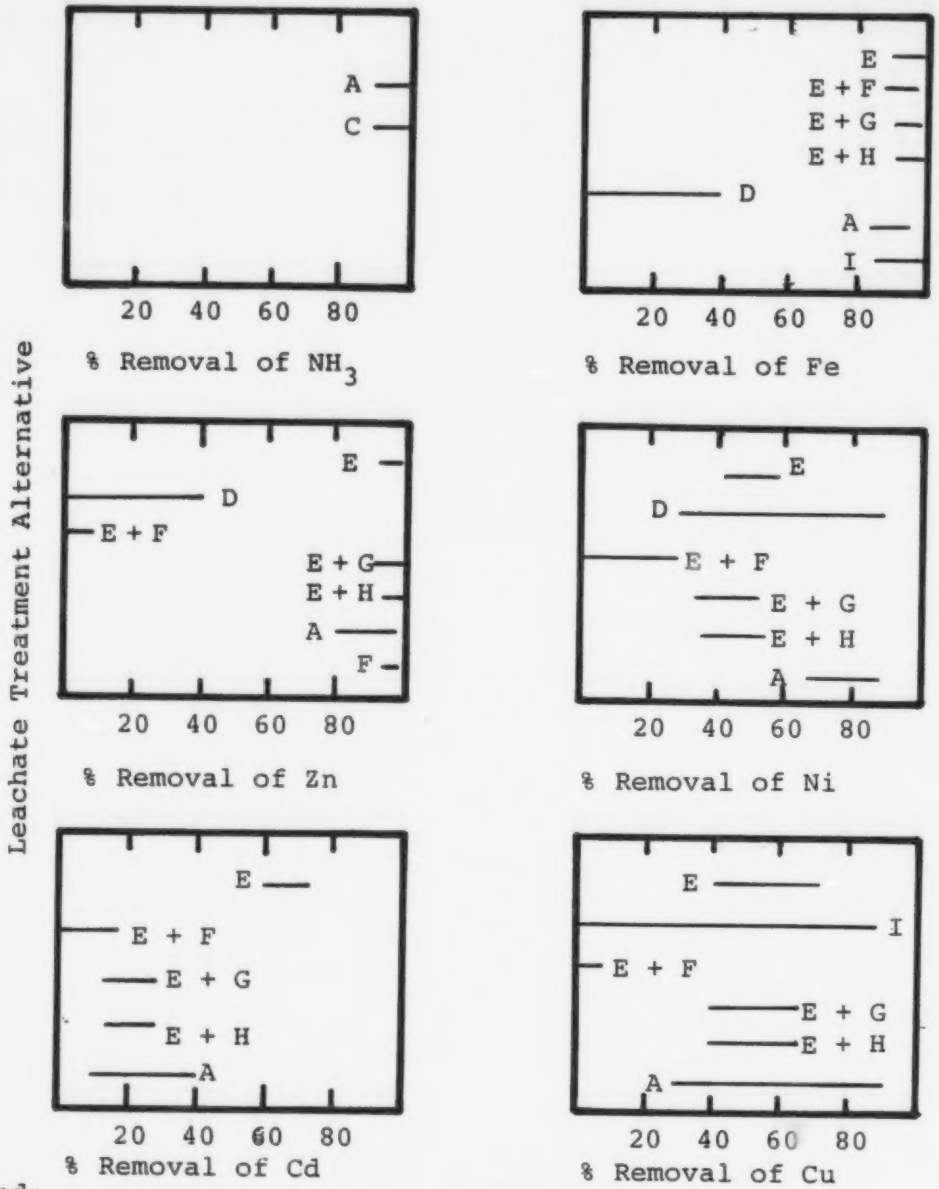


Figure 42. COD removal efficiencies for the treatment of leachates (120).



Legend:

A- Anaerobic Filter	F- NaOCl coagulation
B- Air Stripping	G- Alum Coagulation
C- Activated Sludge	H- NaOH Coagulation
D- Activated Carbon	I- Aerated Lagoon
E- Lime Coagulation	

Figure 43.. % Removal of NH_3, Fe, Zn, Ni, Cd, and Cu by various treatment alternatives (120).

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potential treatment processes are presented in Table 45, according to the calculated removal efficiencies required. For each of the parameters considered, a treatment process is available which can reduce concentrations to meet the discharge standard. An approach utilizing a combination of processes is imperative when treating WWTP sludge leachates.

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Environmental Control

In many cases, environmental controls have been applied to WWTP sludge landfill sites to curb environmental effects such as dust, vectors, odors, etc. Various environmental control practices are outlined in Table 57 (28).

OPERATIONAL CONSIDERATIONS

The design and construction of WWTP sludge landfills has largely been determined by design engineers and site operators, who relied upon experience and cost considerations in their management efforts. Though the EPA and some states have now established sludge landfilling guidelines, many costs associated with these policies are prohibitive.

Among the most costly of the landfilling recommendations are the conditions of sludge stabilization and dewatering. The following section evaluates recommended EPA guidelines for sludge stabilization and dewatering where they apply to current landfilling practices. Also, anticipated compaction of the various WWTP sludges are discussed. A summary of operational characteristics versus the range of solids content is also presented.

Sludge Stabilization

The advantages of landfilling stabilization sludges in sludge landfill operations are: (1) to reduce the leachable fractions of the sludge, (2) to reduce odors, and (3) pathogen population reduction. A substantial reduction in organics is realized only by anaerobic and aerobic digestion and heat treatment processes. As discussed in Sections 3 and 7, odors and pathogens can be curbed by lime treatment, chlorine oxidation, and the aforementioned biological processes.

The question of whether sludge stabilization is necessary for landfilling operations is largely governed by:

- The proximity of the surrounding community to the landfill;
- Physical characteristics of the landfilling site, including soils, geology, hydrology, climate, etc.;

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TABLE 57. ENVIRONMENTAL CONTROL PRACTICES (28)

Control Practices / Environmental Problems	Safety Program	Maintain Washrooms for Personnel	Training Course for New Personnel	Use Safety Clamps on Truck Tailgates	Maintain Road Markings and Trench Barriers	Maintain Fencing	Apply Insecticide	Maintain Buffer Areas, Grass	Proper Equipment Maintenance and Cleaning	Spray Water/Oil/Liquid Asphalt	Truck Wash Pad (to clean trucks)	Maintain Grass Waterways, Diversion Ditches, Rip Rap	Final Grading of Disturbed Areas	Revegetation of Disturbed Areas	Chemical Masking Agent	Lime On Site	Workers Supplied With Aerators	Cover Sludge Daily	Water Diverted Away From Site
Spillage			X	X	X				X							X			
Siltation and Erosion			X					X				X	X	X					X
Mud			X								X	X	X	X					X
Dust			X					X		X	X			X					
Vectors			X			X	X	X			X					X		X	
Odors			X					X			X				X	X	X	X	
Aerosols			X					X									X	X	
Noise			X			X		X	X										
Other Air Pollution			X						X								X		
Aesthetics			X			X	X	X	X		X	X	X	X	X	X	X	X	
Fire Hazard			X					X	X								X	X	
Health		X	X				X									X	X	X	
Safety	X		X	X	X	X				X							X		

* Control practices can be used to prevent or eliminate environmental problems.

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- The design and operational practices of the landfill;
- Definition of the pathogenic aerosol threat posed by unstabilized sludges; and
- Costs.

Public acceptance of sludge landfills can be strongly influenced by the presence or absence of landfill odors and public health risks. The distance between the landfill and the nearest community will largely influence requirements of sludge stabilization. Site physical characteristics, landfill design and operation, will influence the public health risks posed by wastewater sludges. The public health risks of pathogenic aerosols originating from unstabilized sludge requires further definition. Lastly, high capital or operational costs required for stabilization can preclude its utilization.

Sludge Dewatering

The importance of sludge dewatering cannot be overemphasized. Dewatering a sludge from a 5 to a 20% solids concentration reduces volume by three-fourths and results in a more workable, non-fluid material (8). Dewatering removes a substantial portion of sludge contaminants, e.g., an increase in solids concentration from 5% to about 30% results in removal of about 40% of the total nitrogen from the sludge (assuming that up to 50% of the total nitrogen is in the form of NH_4-N) (35). Dewatering also reduces the potential moisture available to leachate once sludge is placed in the landfill.

Figure 39 shows the maximum non-leaching sludge to refuse wet weight ratios as a function of sludge solids content at various landfill depths. Figure 39 considers not only the effects of compaction resulting from landfill surcharge loads, but also leachate generated through primary sludge decomposition and the loss of refuse absorption capacity due to refuse decomposition. Examination of Figure 39 demonstrates a large dependence of the maximum non-leaching sludge to refuse ratios on the depth of the disposed mixture. In general, reducing the depth of sludge or sludge/refuse mixtures can have as great an impact on reducing leachate quantity as a decrease in sludge moisture. Sludge dewatering is imperative to many landfill design and operations from a construction standpoint. Table 58 is developed to outline the important physical characteristics of sludges of different solids content in terms of workability.

OTHER CONSIDERATIONS

Landfilling of WWTP sludges is limited by factors which have been broadly identified as regulatory, environmental, operational,

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TABLE 50. OPERATIONAL CHARACTERISTICS OF SLUDGE*

Range of Solids Content (%) and Characteristics	Support Capabilities	Sludge-only Landfills	Codisposal Landfills
2 - 10 Liquid Slurry	Sludge will not support cover soil or equipment.	Trench - Excessive sludge displacement will occur when soil cover is applied (soil sinks to bottom of trench). Sludge must stabilize (settle) before cover is applied. For narrow trenches, apply cover in such a way to produce a bridging effect. For long trenches, dikes can be constructed. Mound/Layer - Excessive sludge bulking media required. Dike - Requires leachate collection. Substantial soil material needed for dike construction and cover placement.	Sludge can channel through the refuse, thus soil/solid waste dikes need to be built. Construction of dry solid waste lift as an absorbtive layer beneath the fill area prior to sludge application can help sustain sludge channeling. Leachate collection is suggested in wet climates. If sludge is undigested, odor control should be implemented, e.g., soil cover applied immediately after spreading sludge.
10 - 25 Semi-solid slurry or gel	Sludge will support cover soil but not equipment. However, once sufficient cover is applied, equipment can proceed atop sludge, but cautiously.	Trench - For sludges < 15% solids, cover material will displace sludge. Light equipment can cover sludge by spreading sufficient material in front of itself. Subsurface dikes may be needed to contain sludge. Bulking media can aid in operability. Mound/Layer - To be mounted to form lifts, sludge must be mixed with sludge bulking media in a suitable ratio (e.g., 1-3:1, soil:sludge). For mounds/lifts to support light equipment, 1-2 ft soil must be applied on first lift. Dike - Requires leachate collection. Substantial soil needed for dike construction and cover placement.	Sludge is relatively viscous and should be amenable to ramp-type operations with working face slope ≤ 30°, though berms should be provided at toe. Sludge is still very moist and caution must be exercised not to exceed refuse absorbtive capacity.
25 - 35 Putty-like cake	Sludge will support cover soil but not equipment. Equipment can be supported once sufficient cover is applied.	Trench - Sludge still spreads out evenly when dropped from atop. Cover material may be applied by light equipment which spreads sufficient material in front of itself. Mount/layer - To be mounded to form lifts, sludge must be mixed with sludge soils in ratios of roughly 0.5 - 2:1. One ft of cover soil needed to support equipment. Dike - Same as above.	Berms and dikes are no longer necessary to contain sludge if applied atop refuse in ramp-type operations of ≤ 30° slope.
> 35 Cake-like solid	Sludge will support equipment.	Trench - Sludge will support equipment without prior sludge/soil bulking and cover soil. Mound/Layer - Mounds may be constructed without mixing sludge with sludge bulking media. Mounds/lifts may be compacted with 0.5 - 1 ft of soil to aid in equipment support. Requires moderate sludge bulking media. Dike - Sludge may not need diking since no longer spreading out when dropped from atop.	Sludge may be handled like solid waste.

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and economic. Principal constraints not previously delineated, but significant in sludge disposal, will be discussed here.

Regulatory Limitations

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Many regulatory agencies require permits prior to landfill construction and operation. Federal, state, and local regulations and permits exist. At present, sludge has not been singled out for separate legislation whether at the state or federal level, rather it has been included within the statutary scope of regulations concerning any substances generally considered to be pollutants discharged into water or disposed of on land (15). Becuase sludge can be regarded as either a liquid or solid waste, problems are encountered in identifying the legal status of sludge.

Among the major federal statutory provisions affecting sludge landfilling are:

- Federal Water Pollution Control Act (FWPCA) Amendment of 1972. Provides for reduction or elimination of discharges of pollutants into water bodies, resulting in increased production of sludge and limiting options for disposal

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- Resource Conservation and Recovery Act (RCRA) of 1976. Provides site management controls and performance standards for surface and ground-water protection at disposal facilities.
- Safe Drinking Water Act Amendment of 1977. Presence of sludge and sludge residues can affect sources of public water supply.
- National Environmental Policy Act of 1969. Standards designed to maintain quality of receiving waters for protection of beneficial uses. Pretreatment requirements can improve sludge quality.
- Solid Waste Disposal Act of 1977. Supplements or strengthens other regulations under FWPCA affecting sludge management.
- Toxic Substances Control Act of 1976. In strenthening the pretreatment program, this may decrease the toxicity level of sludges from WWTPS.

According to a National Academy of Sciences investigation in 1978, the federal laws mentioned above have two major implications for state and local governments (15): (1) those provisions requiring control of effluents or authorizing grants to cover the cost of new treatment facilities are conducive to increases

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in sludge production and its subsequent burden on state and local resources, and (2) federal restrictions on the use of water and air media force state and local consideration of land as the final repository for sludge. State and local regulations and permits for sludge landfilling are highly variable between jurisdictions. Depending upon the jurisdiction, one or more state or local permits may be required for a WWTP sludge landfill (15). Typical permits may include:

1. Solid waste management permit;
2. Special use permit;
3. Zone change certification for a change in zoning appropriate for a sludge landfill;
4. Highway department permit for entrances on public roads and increased traffic volumes;
5. Construction permit for landfill site preparation.
6. Mining permit for excavations; and
7. Fugitive dust permits.

Costs of Disposal Options

Various studies have indicated that landfilling sludge can offer cost advantages over other methods (e.g., 6,295) while others show landfilling costs similar to other alternatives (e.g., 296 to 298). Analysis of available information on direct costs of sludge disposal options reveals significant variations and inconsistencies. These cost variations are attributable to differences in sludge quality, costs of land, labor, and energy, resources available, facility design, and differing assumptions as to cost categories and cost accounting procedures. These variations and inconsistencies are compounded by the problems of segregating costs associated with sludge management from those of the overall wastewater management system of which sludge is an integral part. In addition, a number of indirect and social costs, including adverse impacts on land values, costs of government in regulation and monitoring, etc., are not readily quantifiable, but should be considered in management decisions.

A 1978 report prepared by the National Research Council for the Environmental Protection Agency (15) compared the estimated costs of sludge management at several U.S. cities. Table 59 illustrates these costs. The direct cost comparisons shown are based on annual costs per unit weight of sludge. Annual costs include amortization of capital expenditures as well as recurring operation and maintenance costs. Although

TABLE 59. ESTIMATED COSTS OF SLUDGE MANAGEMENT AT SEVERAL U. S. CITIES* (15)

City	Cost† for Indicated Option for Sludge Management										
	Pyrolysis	Wet Oxidation	Incineration	Drying	Oil-Dehydration	Composting	Landfill	Liquid Application on Land	Dewatered Application on Land	Ocean Disposal	Lagoon
New York City	51-88	113		87	116						
Washington, D.C.	48-60		57	60-73	41-80	71-86			81-82		
Washington Suburban Sanitary District			69-111				83-99				
Corpus Christi, Texas			111	68				46-59	54-76		
Boston, Massachusetts		59	44				63				
Knoxville, Tennessee			58	67		81	64-78	125			
Southern California Region			33			22	27-53	64		9	
East Bay MUD, California			138	134				117	130	61	138
Denver, Colorado			76-98			135-137		77	87-104		
Sacramento, California			95				60-74	56			
Tampa, Florida			173	101-128			121-141	158-160			
Range	48-88	59-113	33-173	60-128	41-116	22-177	27-141	46-160	54-130	9-61	138

* Costs adjusted to January, 1976, Engineering News Record Construction Cost Index

† Cost in dollars per ton of dry solids

some of the cost variation observed in Table 59 is attributable to differing local conditions and sizes of represented cities, the data in vertical columns suggests significant differences in estimated costs among the studies. Data in horizontal rows suggests that estimated direct costs of options vary, and that savings of direct costs can be realized by selection of the most favorable options for a specific situation. The estimated costs of landfilling compares favorably with other sludge management options. Dramatic savings or high costs for landfilling options are not observed for any city represented.

One of the significant economic constraints to landfilling sludge involves the haul distance from the waste water treatment plant to the landfill. If short distances are involved, this method can prove very economical when compared with other methods. SCS Engineers (28) cited a comparative cost analysis performed by the North Shore Sanitation District in Waukegan, Illinois, to identify the most cost-effective method of sludge disposal for nearly 36.4 Mg (40 tons) of mostly lime conditioned and elutriated activated sludge of 22% solids (vacuum filtration). Figure 44 illustrates the estimated costs (1980) of treatment, transportation and disposal for each alternative. On the basis of the cost evaluations and a maximum distance of 65 miles, (104 km) to the landfill, it was determined that sludge landfilling would provide the most cost-effective alternative for ultimate disposal.

For all sludge management cost considerations, an important distinction must be made between capital and operation and maintenance expenses. If federal or state construction grants exist, selection of sludge management schemes with low operation and maintenance costs, but high capital costs may be encouraged. Without the construction grants program, the present high costs of capital and energy cost escalations makes high capital investment, energy intensive projects such as incineration, pyrolysis, etc. become less attractive sludge disposal alternatives.

Public Acceptance

The role of decision making on many residual landfill related problems today often rests on the public. The receptiveness of neighboring areas to accept WWTP sludges is a function of the socio-economic relationship which these outlying communities share with their rural counterparts. Another important consideration is the availability of land in these outlying areas, which in many instances, is abundant when compared to large metropolitan areas.

Most public decisions on waste disposal appear to be based on the environmental acceptability of the disposal methods.

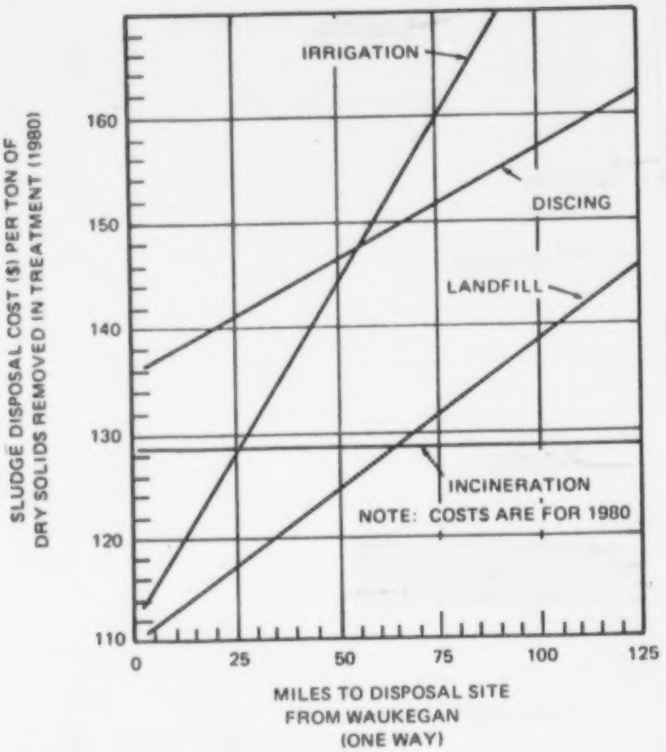

Figure 44. Comparative cost of sludge disposal in Waukegan, Illinois (28).

Some of the concerns most likely to arise during sludge landfill development are listed below:

- Health and safety;
- Traffic;
- Spillage;
- Gas migration;
- Vectors;
- Noise;
- Odor;
- Aesthetics-including site visibility;
- Pre-development land uses and subsequent environmental

impacts;

- Zoning problems/conflicting land uses;
- Ground water pollution and leachate;
- Sedimentation and erosion; and
- Final land use.

The public expects to play an active part in environmental decision-making as both the Clean Water Act of 1977 (PL 95-217) and the Resource Conservation and Recovery Act of 1976 (PL 94-580) mandate public involvement mechanisms and activities. By virtue of these acts, maximum exposure of the public to sludge management decisions are required well in advance of their implementation. Full public participation in preliminary planning stages of sludge landfilling programs should be invited.

SUMMARY

Landfilling of municipal wastewater solids, with or without municipal refuse, can be properly managed to provide protection of the environment and public health. Depending on the haul distance from the wastewater treatment plant to the landfill site, landfilling can be an economical disposal alternative. Like other sludge disposal alternatives, landfilling is subject to a variety of environmental, legal, and institutional constraints which may preclude its implementation or continued use.

The environmental and public health risks associated with sludge landfilling are largely a factor of the characteristics of the sludge, i.e., the treatment the sludge has received, and to site selection, and landfill design operation and maintenance. Major environmental impacts of sludge landfilling include the degradation of ground water and surface water by leachates, and odor and vector problems. With available technology, careful site selection, and use of current techniques in design, construction, maintenance, and water quality monitoring, landfill sites can be established and maintained without significant environmental degradation.

Where feasible, landfilling an admixture of municipal wastewater sludge and municipal refuse is recommended to minimize potential leachate problem costs. The degree of sludge stabilization and dewatering required for landfilling is highly site-specific, though the environmental and cost benefits of dewatering are attractive for any landfilling operation.

REFERENCES

1. Feliciano, D. V. Sludge: Back Into the Ocean? J. Water Pollution Control Federation, 53(10):1442-1446, 1981.

2. Eleventh Annual Report of the Council of Environmental Quality. U.S. Government Printing Office, Washington, D.C., 1980. 90 pp.

3. Engineering News Record. The Spreading Sludge Dilemna. McGraw-Hill, Inc., 201(14):19-21, 1978.

4. Culp, G. L. Handbook of Sludge-Handling Processes: Cost and Performance. Garland Publishing, Inc., New York, New York, 1979. 221 pp.

5. Black, Crow and Eidness. Process Design Manual for Sludge Treatment and Disposal. EPA-625/1-74-006, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1974. 370 pp.

6. Burd, R. S. A Study of Sludge Handling and Disposal. Federal Water Pollution Control Administration, Department of the Interior. Publication No. AP-20-4, 1968. 320 pp.

7. USEPA. Sludge Treatment and Disposal, Sludge Treatment, Volume 1. EPA-625/4-78-012, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 140 pp.

8. Brown and Caldwell, Consulting Engineers. Process Design Manual for Sludge Treatment and Disposal. EPA-625/1-79-011, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1979. 985 pp.

9. Ettlich, W. F., D. J. Hinrichs, T. S. Lineck. Operations Manual, Sludge Handling and Conditioning. EPA 430/9-78-002, U.S. Environmental Protection Agency, Washington, D.C., 1978. 360 pp.

10. Vesilind, T. A. Treatment and Disposal of Wastewater Sludges. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1979. 316 pp.

11. Metcalf and Eddy, Inc. Wastewater Engineering: Collection Treatment, Disposal. McGraw-Hill, New York, New York, 1972. 290 pp.

12. Anderson, C. N. Peak Sludge Loads at a Municipal Treatment Plant. In: Proceedings of the 44th Annual Meeting of the Pacific Northwest Pollution Control Association, Portland, Oregon, 1977. pp. 17-21.

13. Dewante and Stowell and Brown and Caldwell. Final Report, Central Treatment Plant Study, County of Sacramento, Sacramento, California, 1974. 207 pp.

14. Keusch, G. T. Ecology of the Intestinal Tract. Natural History, 83(9):70-79, 1974.

15. U.S. Environmental Protection Agency. Multimedium Management of Municipal Sludge, Volume IX. Commission on Natural Resources, National Research Council. National Academy of Sciences, Washington, D.C., 1978. 170 pp.

16. Ford, D. C. General Sludge Characteristics. In: Water Quality Improvement by Physical and Chemical Processes. University of Texas Press, Austin, Texas, 1970. 165 pp.

17. Furr, A. K., A. W. Lawrence, S. S. C. Tong, M. C. Grandolfo, R. A. Hafstader, C. A. Bache, W. H. Gutenmann, and D. J. Lisk. Multielement and Chlorinated Hydrocarbon Analysis of Municipal Sewage Sludges of American Cities. Environ. Sci. and Tech., 10(7):683-687. 1976.

18. Farrell, J. B. and B. V. Salotto. The Effect of Incineration on Metals, Pesticides, and Chlorinated Biphenyls in Sewage Sludge. In: Proceedings of the National Symposium on Ultimate Disposal of Wastewaters and Their Residuals, F. E. McJunkin and P. A. Vesilind, eds. Water Resources Research Institute, Durham, North Carolina, 1973. pp. 186-198.

19. Palfi, A. Survival of Enteroviruses During Anaerobic Sludge Digestion. In: Advances in Water Pollution Research, S. H. Jenkins, eds. Pergamon Press, Oxford and New York, 1973. pp. 99-104.

20. Farrell, J. B. Overview of Sludge Handling and Disposal. In: Proceedings of the National Conference on Municipal Sludge Management, Pittsburg, Pennsylvania, 1974. pp. 5-10.

21. Malina, J. F., Jr., K. R. Ranganathan, B. E. D. Moore and B. P. Sagik. Poliovirus Inactivation by Activated Sludge. In: Virus Survival in Water and Wastewater Systems. J. F. Malina, Jr. and B. P. Sagik, eds. Center for Research in Water Resources, The University of Texas, Austin, Texas, 1974. p. 95.

22. Black and Veatch, Consulting Engineers. Process Design Manual for Phosphorus Removal. EPA-625/1-76-001a. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 251 pp.

23. Baillod, C. R., G. M. Cressey, and R. T. Beaupre'. Influence of Phosphorus Removal on Solids Budget. J. Water Pollution Control Federation, 49(1):131-145, 1977.

24. Finger, R. E. Solids Control in Activated Sludge Plants with Alum. J. Water Pollution Control Federation, 45(8): 1654-1662, 1973.

25. Farrell, J. B., F. E. Smith, S. W. Hathaway, and R. B. Dean. Lime Stabilization of Primary Sludge. Journal Water Pollution Control Federation, 46(1):113-122, 1974.

26. Wyatt, J. M. and P. E. White. Sludge Processing, Transportation and Disposal/Recourse Recovery: A Planning Perspective. Water Planning Division Report WPD 12-75-01. U.S. Environmental Protection Agency, Washington, D.C., 1979. 98 pp.

27. Cliver, D. O. Virus Associated with Wastewater Solids. Envir. Letters, 10(3):215-223, 1975.

28. SCS Engineers. Process Design Manual for Municipal Sludge Landfills. EPA-625/1-78-010, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 295 pp.

29. Stern, G., and J. B. Farrell. Sludge Disinfection Techniques. In: Proceedings of National Conference on Composting of Municipal Residues and Sludges, Washington, D. C. Information Transfer, Inc., Rockville, Maryland, 1877. pp. 142.

30. U.S. Environmental Protection Agency. Alternative Waste Management Techniques for Best Practicable Waste Treatment. EPA-430/9-75-013, U.S. Environmental Protection Agency, Washington, D.C., 1975. p. 28.

31. Eliassen, R. and J. Trump. High-Energy Electrons Offer Alternative to Chlorine. In: Proceedings of the 45th Annual Conference of the California Water Pollution Control Association, San Diego, California, 1973. pp. 45-51.

32. Haug, R. T., L. D. Tortorici, and S. K. Raksit. Sludge Processing and Disposal. Los Angeles/Orange County Metropolitan Area (LA/OMA) Project. Los Angeles County Sanitation Districts, Whittier, California, 1977. 245 pp.

33. Ware, S. A. A Survey of Pathogen Survival During Municipal Solid Waste and Manual Treatment Processes. EPA-600/8-80-034. U.S. Environmental Protection Agency, Cincinnati, Ohio, August, 1980. 100 pp.

34. PAT Report. Wet Air Oxidation Comes of Age. Envir. Sci. and Tech., 9(4):300-301, 1975.

35. Regional Wastewater Solids Management Program. Carver-Greenfield Process Evaluation. Los Angeles/Orange County Metropolitan (LA/OMA Project). Los Angeles County Sanitation Districts, Whitter, California, 1978. 88 pp.

36. Smith, J. E., Jr. Sludge Conditioning with Incineration Ash. In: Proceedings of the 27th Purdue Industrial Waste Conference, Purdue University, Lafayette, Indiana, 1977. pp. 72-77.

37. Parkhurst, J. D. Landfill Disposal Demonstration Project, Draft Report. Los Angeles County Sanitation Districts, Los Angeles, California, 1978. 102 pp.

38. Swartzbaugh, J. T., R. L. Heintrich, Jr., and G. Sabel. Evaluation of Landfilled Municipal and Industrial Solid Wastes. EPA-68-03-2120. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 61 pp.

39. Stone, R. Disposal of Sewage Sludge Into a Sanitary Landfill. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1974. 291 pp.

40. Broadbent, F. E. Organics. In: Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land. National Association of State Universities and Land-Grant Colleges, Washington, D.C., 1973. pp. 97-102.

41. Levin, P. Disposal Systems and Characteristics of Solid Wastes Generated at Wastewater Treatment Plants. In: Proceedings of the Tenth Sanitary Engineering Conference, University of Illinois, Urbana, Illinois, 1966. pp. 25-30.

42. Hecht, N. L., D. S. Duvall, and A. S. Rashidi. Characterization and Utilization of Municipal and Utility Sludges and Ashes, Volume II, Municipal Sludges. EPA-670-2-75-033B U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 200 pp.

43. Sacramento Area Consultants. Sewage Sludge Management Program Final Report, Vol. 1 SSMP Final Report, Work Plans, Source Survey. Sacramento Regional County Sanitation District, Sacramento, California, 1979. 72 pp.

44. Sacramento Area Consultants. Sewage Sludge Management Program Final Report-Vol. 2, SSB Operation and Performance. Sacramento Regional County Sanitation District, Sacramento, California, 1979. 116 pp.

45. Dacre, J. C. Potential Hazards of Toxic Organic Residues in Sludge. In: Sludge-Health Risks of Land Application, G. Bitton, B. L. Damron, G. T. Edds, and J. M. Davidson, eds. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1980. pp. 85-102.

46. Menzie, C. M. Fate of Pesticides in the Environment. Ann. Rev. Entomol., 17(3):199-222, 1972.

47. Sommers, L. E. Chemical Composition of Sewage Sludges and Analysis of Their Potential Use as Fertilizers. J. Environ. Qual., 7(2):22-232, 1977.

48. Sommers. L. E., D. W. Nelson, and K. Y. Yost. Variable Nature of Chemical Composition of Sewage Sludges. J. Environ. Qual. 5(3):303-306, 1976.

49. Sommers, L. E., M. A. Tabatabai and D. W. Nelson. Forms of Sulfur in Sewage Sludge. J. Environ. Qual., 6(1):42-46, 1977.

50. Klein, L. A., M. Land, N. Nash, and S. L. Kirschner. J. Water Pollution Control Federation, 46(2):2653-2662, 1974.

51. Berrow, J. L., and J. Webber. Trace Elements in Sewage Sludges. J. Sci. Food Agric., 23(1):93-100, 1972.

52. Bloomfield, C., and G. Pruden. The Effects of Aerobic and Anaerobic Incubation on the Extractabilities of Heavy Metals in Digested Sewage Sludge. Environ. Pollut., 8(3):217-232, 1975.

53. Lagerwerff, J. V., G. T. Biersdorf, and D. L. Brower. Retention of Metals in Sewage Sludge: Constituent Heavy Metals. J. Environ. Qual., 5(1):19-23, 1976.

54. Page, A. L. Fate and Effects of Trace Elements in Sewage Sludge When Applied to Agricultural Land. EPA-670-2-74-005, Environmental Protection Agency, Cincinnati, Ohio, 1974. 98 pp.

55. Stover, R. C., L. E. Sommers, and D. J. Silviera. Evaluation of Metals in Wastewater Sludges. J. Water Pollution Control Federation, 48(9):2165-2175, 1976.

56. Silviera, D. J. and L. E. Sommers. Extractability of Copper, Zinc, Lead, and Cadmium in Soils Amended With Sewage Sludge. J. Environ. Qual., 6(1):47-52, 1976.

57. Akin, E. W., H. P. Pahren, W. Jakudowski, and J. B. Lucas. Health Hazards Associated with Wastewater Effluents and Sludge: Microbiological Considerations. In: Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, B. P. Sagik and C. A. Sorber, eds. University of Texas, San Antonio, Texas, 1978. pp. 61-74.

58. Cookson, J. T. The Use of Temporary Wastewater Treatment Plants-Standards and Procedures for Elimination of Health Hazards. Prepared for Montgomery County Council, Maryland, 1972. 125 pp.

59. Stern, G. Pasteurization of Liquid Digested Sludge. In: Proceedings of National Conference on Municipal Sludge Management, Pittsburg, Pennsylvania. Information Transfer, Inc., Rockville, Maryland, 1974. pp. 163-170.

60. Ward, R. L. and J. R. Brandon. Effect of Heat on Pathogenic Organisms Found in Wastewater Sludge. In: Proceedings of National Conference on Composting of Municipal Residues and Sludges, Washington, D.C. Information Transfer, Inc., Rockville, Maryland, 1977. pp. 54-60 pp.

61. Ornevich, R. F. and J. E. Smith, Jr. Pathogen Reduction in Thermophilic Aerobic Digestion Process. In: Proceedings of the 48th Water Pollution Control Federation Conference, Miami Beach, Florida, 1975. pp 112-116.

62. Farrell, J. B. and G. Stern. Methods for Reducing the Infection Hazard of Wastewater Sludge. In: Proceedings of a Symposium on Radiation for a Clean Environment, International Atomic Energy Agency, Vienna, Austria, 1975. pp. 72-79

63. Mitchell R. Introduction to Environmental Microbiology. Prentice-Hall, Inc., New Jersey, 1974. 324 pp.

64. Cliver, D. O. Viral Infections. In: Food Borne Infections and Intoxications, 2nd ed., H. Riemann and F. L. Bryan, eds. Academic Press, Inc., New York, New York, 1979. p. 299.

65. Moore, B. F., B. P. Sagik, and C. A. Sorber, An Assessment of Potential Health Risks Associated With Land Disposal of Residual Sludges. In: Proceedings of Third National Conference on Sludge Management, Disposal and Utilization, Miami Beach, Florida. Information Transfer, Inc., Rockville, Maryland, 1976. p. 108.

66. Ward, R. L. and C. S. Ashley. Inactivation of Poliovirus in Digested Sludge. Applied and Environmental Microbiology, 31(6):921-930, 1976.

67. Bertucci, J. Studies on Inactivation Rates of Five Viruses During Anaerobic Sludge Digestion. Metropolitan Sanitary District of Greater Chicago, 1975. 117 pp.

68. Kabler, P. Removal of Pathogenic Microorganisms by Sewage Treatment Processes. Sewage and Industrial Wastes, 31(11): 1373-1382, 1959.

69. Roediger, H. J. The Technique of Sewage Sludge Pasteurization; Actual Results Obtained in Existing Plants; Economy. Bull. No. 21-31. International Research Group on Refuse Disposal-Information, 1964-1967. 141 pp.

70. Wizigmann, I. and F. Wuersching. Experience With a Pilot Plant for the Irradiation of Sewage Sludge: Bacteriological and Parasitological Studies After Irradiation. In: Proceedings of a Symposium on Radiation for a Clean Environment, International Atomic Energy Agency, Vienna, Austria, 1975. pp. 80-88.

71. Massachusetts Institute of Technology. High Energy Electron Irradiation of Wastewater Liquid Residuals. U.S. National Science Foundation, Washington, D.C., 1977. 45 pp.

72. Reimers, R. S., M. D. Little, D. B. Leftwich, D. D. Bowman, A. J. Englande, and R. F. Wilkinson. Investigation of Parasites in Southern Sludges and Disinfection by Standard Sludge Treatment Processes, EPA Draft Final Report, 1980.

73. Yeager, G. J. Risk to Animal Health from Pathogens in Municipal Sludge. In: Sludge-Health Risks of Land Application, G. Britton, B. L. Damron, G. T. Edds, and J. M. Davidson, eds. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1980. pp. 173-200.

74. Shepard, M. R. N. Helminthological Aspects of Sewage Treatment in Hot Climates. In: Water Wastes and Health in Hot Climates, R. Feachern, M. McGarry, and D. Mara, eds. New York: John Wiley and Sons, 1977. pp. 299-309.

75. Hays, B. D. Potential for Parasitic Disease Transmission With Land Application of Sewage Plant Effluents and Sludges. Water Research, 11(7):583-595, 1977.

76. Foster, D. H. and R. S. Engelbrecht. Microbial Hazards of Disposing of Wastewater on Soil. In: Conference on Recycling Treated Municipal Wastewater Through Forest and Cropland, W. E. Sopper and T. L. Kardos, eds. EPA-660/2-74-003. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1974. pp. 217-241.

77. Rudolfs, W., L. L. Falk, and R. A. Rogotzke. Sewage and Wastes, 23. Series of six papers-I. Bacterial Contamination, pp. 253-268. II. Field and Laboratory Studies on Endamoeba cysts, pp. 478-485. III. Field Studies on *Ascaris* eggs, pp. 656-660. IV. Bacterial Decontamination. pp. 739-751. V. Helminthic Decontamination, pp. 853-860. VI. Application of Results, pp. 992-1000. 1951.

78. Marsh, P. B., P. D. Millner, and J. M. Kla. A Guide to the Recent Literature on Aspergillosis as Caused by *Aspergillus fumigatus*, a Fungus Frequently Found in Self-Heating Organic Matter. Mycopathologia. 69:67-70, 1977.

79. Allen, J. C. Infection and the Compromised Host. The Williams and Wilkins Co., Baltimore, Maryland, 1976. 178 pp.

80. Clark, C. S., H. S. Bjornson, J. W. Holland, T. L. Huge, V. A. Majeti, and P. S. Gartside. Occupational Hazards Associated with Sludge Handling. In: Sludge-Health Risks of Land Application. G. Britton, B. L. Damron, G. T. Edds, and J. M. Davidson, eds. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1980. pp. 215-244.

81. Whitman, Requardt, and Associates. Sludge Utilization Project-Operations, Plans, and Procedures. Report to the Maryland Dept. of Environmental Services, 1973. 143 pp.

82. Walker, J. M., J. L. Ely, P. Hundemann, N. Frankos, and A. Kaminski, Sewage Sludge Entrenchment System for Use by Small Scale Municipalities. EPA-600/2-78-018. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 70 pp.

83. Sikora, L. J., C. M. Murray, N. H. Frankos, and J. M. Walker. Water Quality at a Sludge Entrenchment Site. Ground Water, 16(2):125-132, 1978.

84. Conover, H. S. Grounds Maintenance Handbook, 3rd ed. McGraw-Hill, New York, New York, 1977. 631 pp.

85. Lukasik, G. O. and J. W. Cormack. Development and Operation of a Sanitary Landfill for Sludge Disposal. In: Proceedings of an EPA 208 Seminar, Reston, Virginia, 1977. North Shore Sanitation District, Waukegan, Illinois. 17 pp.

86. Sussman, D. Disposal Operations Mixing Sewage Sludge and Municipal Solid Wastes. Solid Waste Management Refuse Removal 20(8):920-926, 1977.

87. Anon, R. Co-disposal of Sludge with Refuse: Progress, Problems, and Possibilities. Sludge Magazine, 1(2):25-29, 1978.

88. Bonner, A. Ohio Site "Last Chance" for County Trash. Washington Post, 16 December, 1974.

89. Pickart, B. J. Landfilling Milled Refuse Mixed with Digested Sewage Sludge. M. S. Thesis, University of Wisconsin at Madison, 1974. 205 pp.

90. Emcon Associates. Sonoma County Solid Waste Stabilization Study. EPA SW 530 65D. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 228 pp.

91. Johansen, O. J. and D. A. Carlson. Characterization of Sanitary Landfill Leachates. Water Research, 10(10):1129-1134, 1976.

92. SCS Engineers. Investigation of Ground-water Contamination from Subsurface Sewage Sludge Disposal, Volume 2, Case Study Reports. EPA 530/SW-167C. U.S. Environmental Protection Agency, Washington, D.C., 1978, 533 pp.

93. Bradford, G. R., A. L. Page, L. J. Lund, and W. Olmstead. Trace Element Concentrations of Sewage Treatment Plant Effluents and Sludges: Their Interaction with Soils and Uptake by Plants. J. Environ. Qual., 4(1):123-126, 1975.

94. Sweeney, C. D. Leaching Characteristics of Various Heavy Metals and Anions from Municipal Sludge Ash. M.S. Thesis, University of Connecticut, 1978. 320 pp.

95. USEPA. Comparison of NTAC, NAS, and Proposed EPA Numerical Criteria for Water Quality. U.S. Environmental Protection Agency, Washington, D.C., 1973. 13 pp.

96. USEPA. Interim Primary Drinking Water Regulations. U.S. Environmental Protection Agency, Washington D.C., Federal Register, 41(133):28412-28419, July 9, 1976.

EPA-287 (Cin.)
(4-76)

97. USEPA. National Secondary Drinking Water Regulations. U.S. Environmental Protection Agency, Washington, D.C. Federal Register, 42(52):17143-17147, March 31, 1977.

98. California State Water Resources Control Board. Water Quality Control Plan - Ocean Waters of California. Resolution No. 72-45, July, 1972. 125 pp.

99. Whipple, G. C., G. M. Fair, and M. C. Whipple. The Microscopy of Drinking Water, 4th Ed. Wiley, New York, 1948. 290 pp.

100. Stumm, W. and Morgan, J. J. Aquatic Chemistry. Wiley Interscience, New York, 1970. 563 pp.

101. Lu, J. C. S. Studies on the Long-Term Transformations of Trace Metals in the Polluted Marine Sediment-Seawater System. Ph.D. Thesis, University of Southern California, 1976. 252 pp.

102. Degens, E. T. Molecular Nature of Nitrogenous Compounds in Sea Water and Recent Marine Sediments. In: Organic Matter in Natural Waters, D. W. Hood ed., Institute of Marine Sciences, University of Alaska, 1970. pp. 77-106.

103. Siegel, A. Metal-Organic Interactions in the Marine Environment. In: Organic Compounds in Aquatic Environments, S. J. Faust and J. V. Hunter, eds., Marcel Decker, New York, 1971. pp. 265-295.

104. Williams, P. M. The Distribution and Cycling of Organic Matter in the Ocean. In: ORganic Compounds in Aquatic Environments, S. J. Faust and J. V. Hunter, eds., Marcel Decker, New York, 1971. pp. 145-163.

105. Menzel, D. W. and J. H. Ryther. Distribution and Cycling of Organic Matter in the Oceans. In: Organic Matter in Natural Waters, D. W. Hood, ed. Institute of Marine Science, University of Alaska, 1970. pp. 31-54.

106. Bader, R. G., D. W. Hood, and J. B. Smith. Recovery of Dissolved Organic Matter in Sea-Water and Organic Sorption by Particulate Material. In: Geochimica et Cosmochimica Acta, 19(4):236-243, 1971.

107. Barber, R. T. Dissolved Organic Carbon from Deep Waters Resists Microbial Oxidation. Nature, 220(5164):274-275, 1968.

108. Williams, P. M. Organic Acids Found in Pacific Ocean Waters. Ph.D. Thesis, University of California at Los Angeles, 1960. 225 pp.

EPA-287 (Cin.)
(4-76)

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109. Pratt, P. R., F. E. Braodbent, and J. P. Martin. Using Organic Wastes as Nitrogen Fertilizers. Calif. Agr., 27(6):10-13, 1973.

110. Keeney, D. R., K. W. Lee, and L. M. Walsh. Guidelines for the Application of Wastewater Sludge to Agricultural Land in Wisconsin. Tech. Bull. No. 88, Dept. of Natural Resources, Madison, Wisconsin, 1975. 95 pp.

111. Ryan, J. A., D. R. Keeney, and L. M. Walsh. Nitrogen Transformation and Availability of an Aerobically Digested Sewage Sludge in Soil. J. Environ. Qual., 2(4):489-492, 1973.

112. King, L. D. Mineralization and Gaseous Loss of Nitrogen in Soil. Applied Liquid Sewage Sludge. J. Environ. Qual., 2(3):356-358, 1973.

113. Lund, L. J., A. C. Page and C. O. Nelson. Nitrogen and Phosphorus Levels in Soils Beneath Sewage Disposal Ponds. J. Environ. Qual., 5(1):26-30, 1976.

114. Stevenson, F. J. Role and Function of Humus in Soil with Emphasis on Adsorption of Herbicides and Chelation of Micronutrients. Bioscience, 22(11):643-650, 1972.

115. Engelbrecht, R. S. Survival of Viruses and Bacteria in a Simulated Sanitary Landfill. NTIS/PB-234 589, National Technical Information Service, Springfield, Virginia, 1973. 104 pp.

116. Glotzbecker, R. A., and A. L. Novello. Poliovirus and Bacterial Inidators of Fecal Pollution in Landfill Leachates. News of Environmental Research in Cincinnati, U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio, January 31, 1975. 12 pp.

117. Sobsey, M. D., C. Wallis, and J. L. Melnick. Studies on the Survival and Fate of Enteroviruses in an Experimental Model of a Municipal Solid Waste Landfill and Leachate. Applied Microbiology, 30(4):565-574, 1975.

118. Engelbrecht, R. S. and P. Amirhor. Inactivation of Enteric Bacteria and Viruses in Sanitary Landfill Leachate. NTIS/PB-252 973/AS, National Technical Information Service, Springfield, Virginia, 1975. 104 pp.

119. Riley, R. D., R. G. Benedict, R. W. Seabloom, and D. A. Carlson. Chemical and Microbiological Studies on Leachates from a Waste Tip. J. Applied Bacteriology, 42(2): 285-288, 1977.

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EPA-287 (Cin.)
(4-76)

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120. Lu, J. C. S., R. J. Stearns, and R. D. Morrison. Leachate Production and Management from Sludge Landfills: Summary and Assessment. Draft Final. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1981. 356 pp.

121. Brown, R. E. Significance of Trace Metals and Nitrates in Sludge Soils. J. Water Pollution Control Federation, 47(12):2863-2875, 1975.

122. Larson, W. E. and R. H. Dowdy. Heavy Metals Contained in Runoff from Land Receiving Wastes. In: Disposal of Residue on Land. Information Transfer, Rockville, Maryland, 1976. pp. 21-26.

123. Hinesly, T. D. and R. L. Jones. Heavy Metal Contents in Runoff and Drainage Waters from Sludge-Treated Field Lysimeter Plots. In: Disposal of Residues on Land. Information Transfer, Rockville, Maryland, 1976. pp. 27-44.

124. Walker, J. M., W. D. Burge, R. L. Chaney, E. Epstein, and J. D. Menzies. Trench Incorporation of Sewage Sludge in Marginal Agricultural Land. EPA-600/2-75-034. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 220 pp.

125. Lejcher, T. R. and S. H. Kunkel. Restoration of Acid Spoil Banks with Treated Sewage Sludge. In: Conference on Recycling Treated Municipal Wastewater Through Forest and Cropland. EPA 660/2-74-003. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1974. pp. 165-178.

126. Purushottam, D., G. R. Tamke, and C. M. Stoffel. Leachate Production at Sanitary Landfill Sites. J. Environmental Engineering Division, ASCE, 103(EGG):981-988, 1977.

127. Remson, I., A. A. Fungaroli, A. W. Lawrence. Water Movement in an Unsaturated Sanitary Landfill. J. of Sanitary Engineering Division, ASCE, 94(542):307-317, 1968.

128. Fenn, D. G., K. J. Hanley, T. V. DeGeare. Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites. EPA/530/SW-168, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975.

129. Lutton, R. J., G. L. Regan, and L. W. Jones. Design and Construction of Covers for Solid Waste Landfills. EPA-600.2-79-165, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1979. 249 pp.

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EPA-287 (Cin.)
(4-76)

130. Perrier, E. R. and A. C. Gibson. Hydrologic Simulation on Solid Waste Disposal Sites (HSSWDS). SW-868. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980. 51 pp.

131. Caffrey, R. P. and R. K. Ham. The Role of Evaporation in Determining Leachate Production from Milled Refuse Landfills. Compost Science, 6(2):11-15, 1974.

132. Rovers, F. A. and G. J. Farquhar. Infiltration and Landfill Behavior. J. Environmental Engineering Div., ASCE, 99(EES):671-690, 1973.

133. Dilaj, M., and J. F. Lenard. Leachate Control at Landfills Based on Hydrogeological Studies. Public Works, 111(2):93, 1975.

134. Merz, R. C. Investigation of Leaching of a Sanitary Landfill. California State Water Pollution Control Board, Sacramento, California, 1954. 91 pp.

135. Charlies, W. A., R. E. Wardwell, and O. B. Andersland. Leachate Generation from a Sludge Disposal Area. J. Envir. Eng. Div. ASCE. 105(EES):947-960, 1979.

136. Leffel, R. E. Direct Environmental Factors at Municipal Wastewater Treatment Works. EPA-430/9-76-003, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 104 pp.

137. Kenline, P. A., and P. V. Scarpino. Bacterial Air Pollution from Sewage Treatment Plants. Amer. Ind. Hyg. Assoc. J., 33(5):346-353, 1972.

138. King, E. D., R. A. Mill, and C. H. Lawrence. Airborne Bacteria from an Activated Sludge Plant. J. Environ. Health, 36(1):50, 1973.

139. Randall, C. W., and J. O. Ledbetter: Bacterial Air Pollution from Activated Sludge Units. Amer. Ind. Hyg. Assoc. J., 27(6):506-519, 1966.

140. Sorber, C. A., S. Schaub, and H. T. Bausum. An Assessment of a Potential Virus Hazard Associated with Spray Irrigation of Domestic Waste-Waters. In: Virus Survival in Water and Wastewater Systems, J. F. Malina and B. P. Sagik, eds., Univ. of Texas Press, Austin, Texas, 1974. pp. 241-252.

141. Fannin, K. F., J. C. Spendlove, K. W. Cochran, and J. J. Gannon. Airborne Coliphages from Wastewater Treatment Facilities. Applied and Environ. Microbiol., 31(5):705-710, 1976.

142. Stone, R. Preventing Underground Movement of Methane from Sanitary Landfills. J. Civil Engineering Division, ASCE, 48(1):51-53, 1978.

143. Moore, C. A. and I. S. Rai. Design Criteria for Gas Migration Control Devices. In: Management of Gas and leachate in Landfills. U.S. Environemtnal Protection Agency, Cincinnati, Ohio, 1977. pp. 88-94.

144. Engineering Science, Inc. Final Report-In-Situ Investigation of Movement of Gases Produced from Decomposing Refuse. California State Water Control Baord. Publication 35, Sacramento, California, April, 1967. 162 pp.

145. Spencer, W. F., and M. M. Claith. Transfer of Organic Pollutants Between the Solid-Air Interface. In: Fate of Pollutants in the Air and Water Environments, Part I., I. H. Saffet, ed., John Wiley and Sons, New York, 1977. pp. 107-109.

146. Shen, T. T., and T. J. Tofflemire. Air Pollution Aspects of Land Disposal of Toxic Wastes. J. Env. Eng. Division, ASCE, 50(2):211-226, 1980.

147. Carlson, J. A. Recovery of Landfill Gas at Mountain View, Engineering Site Study, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 202 pp.

148. Fungaroli, A. A., and R. L. Steiner. Investigation of Sanitary Landfill Behaviour. Volume I. Final Report. EPA-600/2-79-053a. U.S. Environmental Protection Agency, Cincinnati, Ohio, July, 1979. 308 pp.

149. Reinhart, J. J. and R. K. Ham. Solid Waste Milling and Disposal on Land Without Cover. EPA SW 530 62D1. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 220 pp.

150. Anderson, C. R. and R. K. Ham. Pollutant Production from Milled and Unprocessed Refuse. Olin Avenue Studies. Waste Age, 1(8):21-29, 1974.

151. USEPA. Anaerobic Sludge Digestion, Operations Manual. EPA 430/9-76-001. U.S. Environmental Protection Agency, Washington, D.C., 1976. 124 pp.

EPA-287 (Cin.)
(4-76)

152. Schmidt, J., D. Pennington, and J. McCormick. Ecological Impact of the Disposal of Municipal Sludge onto the Land. In: Proceedings of the 1975 Conference on Municipal Sludge Management and Disposal. Information Transfer, Rockville, Maryland, 1975. pp. 156-168.

153. Gaby, W. L. Evaluation of Health Hazards Associated with Solid Waste/Sewage Sludge Mixtures. EPA-670/2-75-023. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 44 pp.

154. SCS Engineers. Health Effects Associated with Wastewater Treatment and Disposal Systems, State-of-the-Art Review. EPA-600/1-79-016 a,b. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1979. 434 pp.

155. Dreisbach, R. H. Handbook of Poisoning: Diagnosis and Treatment. Lange Medical Publication, Los Altos, California, 1971. 175 pp.

156. Sawyer, C. N. and P. L. McCarty. Chemistry for Environmental Engineering, Third Edition. McGraw-Hill Book Company, New York, 1978. 519 pp.

157. Freeman, R. A. Textbook of Microbiology, Twenty-First Edition. W. B. Saunders Company, Philadelphia, Pennsylvania, 1979. pp. 272-273.

158. Carnow, B., R. Northrop, R. Wadden, S. Rosenberg, J. Holden, A. Neal, L. Shaeff, P. Shaff, and S. Meyer. Health Effects of Aerosols Emitted from an Activated Sludge Plant. EPA-600/1-79-019. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1979. 151 pp.

159. Fiscus, D., E. Gordon, M. Schrag, and L. Shannon. Assessment of Bacteria and Virus Emissions at a Refuse Derived Fuel Plant and Other Waste Handling Facilities. EPA-600/2-78-152, U.S. Environmental Protection Agency, Cincinnati, Phio, 1978. 220 pp.

160. Cliver, D. O. Infection with Minimal Quantities of Pathogens. H. Pahren and W. Jakubowski, eds. EPA-600/9-80-028, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980. pp. 78-89.

EPA-287 (Cin.)
(4-76)

161. Clark, C. S., H. S. Bjornson, J. W. Holland, V. J. Elia, V. A. Majeti, C. R. Meyer, W. F. Balistreri, G. L. Van Meer, P. S. Gartside, B. L. Specker, C. C. Linnemann, Jr., R. Jappa, P. V. Scarpino, K. Brenner, W. J. Davis-Hoover, G. W. Barrett, T. S. Anderson, and D. L. Alexander. Evaluation of the Health Risks Associated with the Treatment and Disposal of Municipal Wastewater and Sludge. EPA-600/S1-81-030. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1981. 228 pp.

162. Northrop, R. L., B. Carnow, R. Wadden, S. Rosenberg, A. Neal, L. Sheaff, J. Holden, S. Meyer and P. Scheff. Health Effects of Aerosols Emitted from an Activated Sludge Plant. In: Wastewater Aerosols and Disease. EPA-600/9-80-028, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980. pp. 180-227.

163. Johnson, D. E., D. E. Camann, J. W. Register, R. J. Prevost, J. B. Tillery, R. E. Thomas, J. W. Taylor, and J. M. Hosenfeld. Health Effects from Wastewater Aerosols at a New Activated Sludge Plant: John Egan Plant, Schaumburg, Illinois. In: Wastewater Aerosols and Disease. EPA-600/9-80-028, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980. pp. 136-157.

164. Kominsky, j. R. Nonviable Contaminants from Wastewater: Hexachloropentadiene Contamination of a Municipal Wastewater Treatment Plant. In: Wastewater Aerosols and Disease. EPA 600/9-80-028, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980. pp. 36-45.

165. American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1977. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1977. 25 pp.

166. Webb, S. J. Factors Affecting the Viability of Air-Borne Bacteria, II. The Effect of Chemical Additives in the Behavior of Air-Borne Cells. J. of Canadian Microbiology, 6:71-88, 1960.

167. Clark, C. S., E. J. Cleary, G. M. Schiff. Disease Risk of Occupational Exposure to Sewage. J. Environ. Eng. Div., ASCE, 102*EES):375-380, 1976.

168. Clark, C. S., A. B. Bjornson, G. M. Schiff, J. P. Phair. Sewage Worker's Syndrome. Lancet, 1(48):1009, 1977.

169. Rylander, R., K. Anderson, C. Belin, and G. Berglund. Sewage Worker's Syndrome. Lancet, 2(23):478-479, 1976.

EPA-287 (Cin.)
(4-76)

170. Dean, R. B. Assessment of Disease Rates Among Sewer Workers in Copenhagen, Denmark. EPA-600/1-78-007, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 48 pp.

171. Horrocks, H. W. Experiments Made to Determine the Conditions Under Which "Specific" Bacteria Derived from Sewage May Be Present in the Air of Ventilating Pipes, Drains, Inspection Chambers and Sewers. Proc. Royal Soc. Longon, Ser. B, 79:231-255, 1907.

172. Winslow, C. E. A., and D. M. Belcher. Changes in the Bacterial Flora of Sewage During Storage. J. Infect. Disease, 1:170, 1904.

173. Johnson, D. E., D. E. Camann, C. A. Sorber, B. F. Sagik, and J. P. Glennon. Aerosol Monitoring for Microbial Organisms Near a Spray Irrigation Site. In: Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges. B. F. Sagik and C. A. Sorber, eds. Center for Applied Research and Technology, U. of Texas, San Antonio, 1978. pp. 231-239.

174. Johnson, D. E., J. W. Register, D. E. Camann, C. H. Millstein, and J. L. Gulinson. Evaluation of the Health Effects Associated with the Application of Wastewater to Land. Draft Phase I Report, SWRI Proj. 01-4297-00, U.S. Army Med. Res. and Dev. Com., Ft. Detrick, Md., 1976. 75 pp.

175. Nelson, K. Capture of Aerosol Particles by Spherical Collectors. J. Air Poll. Control Assoc., 8(8):34-42, 1974.

176. Sorber, C. A., H. T. Bausum, S. A. Schaub, and M. L. Small. A Study of Bacterial Aerosols at a Wastewater Irrigation Site. J. Water Poll. Control Federation, 48(12):2367-2379.

177. Randall, C. W. and J. O. Ledbetter. Bacterial Air Pollution from Activated Sludge Units. Amer. Ind. Hygiene Assoc. Jour., 27(5):506-519, 1966.

178. Camann, D. E., C. E. Sorber, B. P. Sagik, J. P. Glennon, and D. E. Johnson. A Model for Predicting Pathogen Concentrations in Wastewater Aerosols. In: Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludge. B. P. Sagik and C. A. Sorber, eds. Center for Applied Research and Technology. University of Texas at San Antonio, 1978. pp. 240-271.

EPA-287 (Cin.)
(4-76)

179. Millner, P. D., D. A. Bassett, and P. B. Marsh. Dispersal of Aspergillus Fumigatus from Sewage Sludge Compost Piles Subjected to Mechanical Agitation in Open Air Appl. Env. Microbiol. 39(5):1000-1009, 1980.

180. Clark, C. S., H. S. Bjornson, J. W. Holland, T. J. Huge, V. A. Majeti, and P. S. Gartside. Occupational Hazards Associated with Sludge Handling. In: Sludge-Health Risks of Land Application, G. Bitton, B. L. Damron, G. T. Edds, and J. M. Davidson, eds. Ann Arbor Science, Inc. 1980. pp. 215-244.

181. Mattsby, T. and R. Rylander. Clinical and Immunilogical Findings in Workers Exposed to Sewage Dust. J. of Occupt. Med. 20(10):690-692, 1978.

182. Millner, P. D., P. B. Marsh, R. B. Snowden, and J. F. Parr. Occurrence of Aspergillus Fumigatus During Composting of Sewage Sludge. Appl. Env. Microbiol., 34(6):765-772, 1977.

183. Hickey, J. L. S., and P. C. Reist. Health Significance of Airborne Microorganisms from Wastewater Treatment Processes Part I. Summary of Investigations, Part II. Health Significance and Alternatives for Action. J. Water Pollution Control Federation, 47(12):2741, 1975.

184. Ladd, F. C. Airborne Bacteria from Liquid Waste Treatment Units. M.S. Thesis, Oklahoma State Univ., Stillwater, Oklahoma, 1966. 195 pp.

185. King, E. D., R. A. Mill, and C. H. Lawrence. Airborne Bacteria from an Activated Sludge PLant. J. Environ. Health, 36(1):50, 1973.

186. Bringmann, G. and G. Trolldenier. Distance of Coliform Transport by Agricultural Sewage Spraying in Relation to Wind Velocity, Air Humidity, and Ultraviolet Radiation. Gesundheitsing, 81:268, 1960.

187. Busvine, J. R. Arthropod Vectors of Disease. Crane, Russak and Company, Inc., New York, 1975. 75 pp.

188. Snow, K. R. Insects and Disease. John Wiley and Sons, New York, 1974. 121 pp.

189. Page, A. L. and P. F. Pratt. Effects of Sewage Sludge on Effluent Application of Soil, on the Movement of Nitrogen, Phosphorus, Soluble Salts, and Trace Metals to Groundwaters. In: Municipal Sludge Management and Disposal, Information Transfer, Inc., Rockville, Maryland, 1975. pp. 179-187.

EPA-287 (Cin.)
(4-76)

190. Gelprin, A. The Health Effects of Nitrates in Water. Nitrate and Water Supply: Source and Control. In: Proceedings of the 12th Sanitary Engineering Conference, Chicago, Illinois, 1970. pp. 51-52.

191. Pratt, P. F., W. W. Jones, and H. D. Chapman. Changes in Phosphorus in an Irrigated Soil During 28 Years of Differential Fertilization. Soil Sc. 82(4):295-306, 1956.

192. William, C. H. and D. J. David. The Effect of Superphosphate on the Cadmium Content of Soils and Plants. Aust. J. Soil Res. 11(1):43-56, 1973.

193. Hook, J. E., L. T. Kardos, and N. E. Sopper. Land Disposal of Wastewaters on Soil Phosphorus Relations. In: Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland. Pennsylvania State University Press, Pennsylvania, 1973. pp. 45-51.

194. King, L. D. and H. D. Morris. Land Disposal of Liquid Sewage Sludge: III. The Effects of Soil Nitrate. J. Environ. Quality 1:442-446, 1972.

195. Kardos, L. T. and W. E. Sopper. Renovation of Municipal Wastewater Through Land Disposal by Spray Irrigation. In: Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland. Pennsylvania State University Press, Pennsylvania, 1973. pp. 148-163

196. Lofy, R. T., H. T. Phung, R. P. Stearns, and J. J. Walsh. Investigation of Groundwater Contamination of Subsurface Sewage Sludge Disposal. Volume 1. EPA 68-01-4166. U.S.Environmental Protection Agency, Washington, D.C., 1978. 99 pp.

197. Fleischer, M., A. F. Sarofim, D. W. Fassett, P. Hammond, H. T. Shacklette, I. C. T. Nisbet, and S. Epstein. Environmental Impacts of Cadmium: A Review by the Panel on Hazardous Trace Substances. Environmental Health Perspectives 7(7):253-323, 1974.

198. Page, A. L. and F. T. Bingham. Cadmium Residues in the Environment. Residue Reviews, Vol. 48: Residues of Pesticides and Other Contaminants in the Total Environment, F. A. Gunther, ed., New York: Springer-Verlag, 1973. pp. 1-44.

199. Flick, D. F., M. F. Kraybill, and J. M. Dimitroff. Toxic Effects of Cadmium: A Review. Environmental Research 4(2):71-85, 1971.

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TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

200. Page, A. L. Fate and Effects of Trace Elements in Sewage Sludge When Applied to Agricultral Lands. EPA-670/2-74-005. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1974. 90 pp.

201. Weber, J. B. Interaction of Organic Pesticides with Particulate Matter in Aquatic and Soil Systems. In: Fate of Organic Pesticides in the Aquatic Environment. American Chemical Society, Washington, D.C., 1972. pp. 55-120.

202. Weber, J. B. Fate of Organics in Sludges Applied to the Land. In: Proceedings of Fifth National Conference on Acceptable Sludge Disposal Techniques, Orlando, Florida. Information Transfer, Inc., Rockville, Maryland, 1978. pp. 117-124.

203. Van Bladel, R. and A. Moreale. Adsorption of Fenuron and Monuron (Substantial Areas) by Two Montmorillomite Clays. Soil Science Proceedings, 38(6):244-249, 1974.

204. Griffin R. A., A. K. Au, and E. S. K. Chain. Mobility of Polychlorinated Biphenyls and Dicamba in Soil Materials: Determination by Soil Thin-Layer Chromatography. In: Proceedings Eighth Conference on Municipal Sludge Management, Miami Beach, Florida. Information Transfer, Inc., Rockville, Maryland, 1979. pp. 183-189.

205. Hague, R., D. W. Schmedding, and V. H. Freed. Aqueous Solubility, Adsorption, and Vapor Behavior of Polychlorinated Biphenyl Aroclor 1254. Environ. Sci. Technol. 8(1):139-142, 1974.

206. Hague, R., and D. Schmedding. Studies on the Adsorption of Selected Polychlorinated Biphenyl Isomers on Several Surfaces. J. Environ. Sci. Health, 11(2):129-137, 1976.

207. Griffin, R. A., R. Clark, M. Lee, and E. S. K., Chian. Disposal and Removal of Polychlorinated Biphenyls in Soil. In: Land Disposal of Hazardous Waste, David Schultz, ed. EPA-600/9-77-017. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. pp. 169-181.

208. Tucker, E. S., W. J. Litschgi, and W. M. Mees. Migration of Polychlorinated Biphenyls in Soil Induced by Percolating Water. Bull. Environ. Contamin. Toxicol., 13:86-93, 1975.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
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3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

209. Scharpensell, H. W., B. K. G. Theng, and S. Sephan. Polyschlorinated Biphenyls (^{14}C) in Soils: Adsorption, Infiltration, Translocation, and Decomposition. In: Environmental Biogeochemistry and Geomicrobiology, Volume 2: The Terrestrial Environment. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1978. pp. 619-637.

210. International Research Group on Refuse Disposal. Information Bulletin Nos. 1-12. U.S. Department of HEW, Public Health Service, December, 1961 through May, 1963.

211. Englebrecht, R. S. Survival of Viruses and Bacteria in a Simulated Sanitary Landfill. NTIS/PB-234 589, National Technical Information Service, Springfield, Virginia, 1973.

212. McGauhey, P. H. and R. B. Krone. Soil Mantle as a Wastewater Treatment System. Sanit. Engr. Res. Lab., University of California, S.E.R.L. Report 67-11, 1967. 72 pp.

213. Gerba, C. P., C. Wallis, and J. L. Melnick. Fate of Wastewater Bacteria and Viruses in Soil. J. Irrigation Div. ASCE, 101(IR3):214-219, 1972.

214. Sorber, C. A. Protection of the Public Health. In: Land Disposal of Municipal Effluents and Sludges. EPA-902/9-73-001. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1973. pp. 133-137.

215. Merrell, J. C., and W. F. Jopling, R. F. Bott, A. Katko, and H. E. Pintler. The Santee Recreation Project, Santee, California, Final Report. U.S. Dept. of Interior Water Poll. control Res. Publ. No. WP-20-7, 1972. 95 pp.

216. Eliassen, R., P. Douger, and W. Drewry. Stuides on the Movement of Viruses in Groundwater. Progress Report to the Commission on Environmental Hygiene of the Armed Forces Epidemiological Baord, 1965. 45 pp.

217. Drewry, W. A., and R. Eliassen. Virus Movement in Ground Water. Water Pollution Control Fed., 46(4):257-265, 1968.

218. Krone, R. B. The Movement of Disease Producing Organisms Through Soils. In: Proceedings of a Symposium on Municipal Sewage Effluent for Irrigation, Ruston, Louisiana, 1969. pp. 65-72.

219. Burge, W. D. Bacteria and Viruses in Soil/Sludge Systems. In: Fifth National Conference on Acceptable Disposal Techniques. Technology Transfer, Rockville, Maryland, 1978. pp. 125-129.

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
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TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

220. Rudolfs, W., L. L. Falk, and R. A. Ragotzkie. Literature Review on the Occurrence and Survival of Enteric, Pathogenic, and Relative Organisms in Soil, Water, Sewage, and Sludge and on Vegetation, I. Bacterial and Viral Diseases. Sewage and Wastes, 22(12)1261-1269, 1950.

221. State of California Wqter Resources Control Board. State-of-the-Art Review of Health Aspects of Wastewater Reclamation for Groundwater Recharge, 1975. 35 pp.

222. Perhac, R. M. Distribution of Cd, Co, Cu, Fe, Mn, Ni, Pb, and Zn in Dissolved and Particulate Solids from Two Streams in Tennessee. J. of Hydrology, 15(2):177-186, 1972.

223. Eichelbergr, J. W. and J. J. Lichtenberg. Persistence of Pesticides in River Water. Environ. Science and Technology, 5(4):541-544, 1971.

224. Crump-Wiesner, H. J., H. R. Feltz, and M. L. Yates. A Study of the Distribution of Polychlorinated Biphenyls in the Aquatic Environment. U.S. Geological Survey J. of Research, 1(5):603-607, 1973.

225. Smith, R. J. Relationships of Indicator and Pathogenic Bacteria in Stream Waters. J. Water Pollution Control Federation, 45(8):1736-1745, 1973.

226. Phair, J. P. Infection and Resistance: A Review. In: Wastewater Aerosols and Disease, H. Pahren and W. Jakubowski, eds. EPA-600/9-80-028. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980. pp. 71-77.

227. National Institute of Environmental Health Services. Nitrates, Nitrites and Methemoglobinemia. Environmental Review No. 2. Department of Health, Education and Welfare, 1970. 42 pp.

228. USEPA. Nitrogenous Compounds in the Environment. EPA-5AB-73-001. U.S. Environmental Protection Agency, Washington, D.C., 1973. 89 pp.

229. Johnson, J. E. The Public Health Duplications of Widespread Use of the Phenoxy Herbicides and Picloram. Bioscience, 21(17):899-905, 1971.

230. Stone, R. Land Disposal of Sewage and Industrial Wastes. Sewage and Industrial Wastes, 25(4):325-330, 1953.

231. Dorn, C. R. and D. N. Lamphere. Animal and Public Health on Farms Receiving Municipal Sludge. Presented at the XXIth World Veterinary Congress, Moscow, U.S.S.R., July 4, 1979. Ohio State University, Columbus, Ohio. 5 pp.

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BOTTOM OF IMAGE AREA. OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

232. Powell, L. J. Farm Waste Disposal and Its Effect on Human Health. Public Health, London, 88(3):141-153, 1974.

233. Makeig, K. S. The Use of Natural Buffers for Sludge Leachate Attenuation. In-house Report, Dames and Moore, Washington, D.C., 1981, 12 pp.

234. K. W. Brown and Associates, Inc. Hazardous Waste Land Treatment. EPA-SW-874, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980. 891 pp.

235. Matrecon, Inc. Lining of Waste Impoundment and Disposal Facilities. EPA-SW-870, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980. 235 pp.

236. Shultz, D. W. and M. P. Milkas, Jr. Assessment of Liner Installation Procedures. In: Proceedings of the Sixth Annual Research Symposium on Disposal of Hazardous Wastes. EPA-600/9-80-010, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1980. pp. 135-159.

237. Ware, S. A. and G. S. Jackson. Liners for Sanitary Landfills and Chemical and Hazardous Waste Sites. EPA-600/9-78-005, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 77 pp.

238. Haxo, H. E., R. S. Haxo, and T. F. Kellogg. Liner Material Exposed to Municipal Solid Waste Leachate, Third Interim Report. EPA-600/2-79-038, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1979. 45 pp.

239. Haxo, H. E., and R. M. White. Evaluation of Liner Materials Exposed to Leachate, Second Interim Report. EPA-600/2-76-255, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 53 pp.

240. Tolman, A. L., A. P. Ballestero, Jr., W. W. Beck, Jr., and G. H. Emrich. Guidance Manual for Minimizing Pollution from Waste Disposal Sites. EPA-600/2-78-142, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 77 pp.

241. Karol, R. H. Chemical Grouting Technology. J. Soil Mech. Found. Div., ASCE, 94(2):175-204, 1968.

242. Halliburton Services. Grouting in Soils, Vol. 2, Design and and Operations Manual. NTIS/PB-259 044, National Technical Information Service, Springfield, Virginia, 1976. 29 pp.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
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EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
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CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

243. Kapp, M. S. Slurry-trench Construction for Basement Wall of World Trade Center. J. Civil Engineering Division, ASCE, 39(1):36-40, 1969.

244. Gerwick, B. C., Jr. Slurry-trench Techniques for Diaphram Walls in Deep Foundation Construction. J. Civil Engineering Division ASCE, 37(1):70-72, 1967.

245. Engineering News-Record. Bentonite Slurry Stabilizer Trench Keeps Groundwater Out. In: Field and Office Manual. McGraw Hill, Inc., New York, 1965. pp. 70-73.

246. American Colloid Company. Use of Bentonite as a Soil Sealant for Leachate Control in Sanitary Landfills. Skokie, Illinois, 1975. 36 pp.

247. Los Angeles County Sanitation District. Puente Hills Leachate Barrier, Plan of Study. In-house Report. Nov., 1979. 32 pp.

248. Emrich, G. H., W. W. Beck, Jr., and A. L. Tolman. Topsealing to Minimize Leachate Generation. In: Proceedings of the Sixth Annual Research Symposium on Disposal of Hazardous Waste. EPA-600/9-80-010, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980. pp. 274-283.

249. Raymond Internation, Inc. Siroc Grout Technical Manual, New York, 1967. 16 pp.

250. American Cyanamid Company. All About Cynamid AS-9, Chemical Grout. Wayne, New Jersey, 1975. 95 pp.

251. Walker, J. M., L. Ely, P. Hundemann, N. Frankos and A. Kaminski. Sewage Sludge Entrenchment System for Use by Small Municipalities. EPA-600/2-78-018, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 70 pp.

252. Nobel, D. G. well Points for Dewatering Groundwater. Groundwater, 1(3):21-36, 1963.

253. Gregg, D. O. Protective Pumping to Reduce Aquifer Pollution. Glynn County, Louisiana. Groundwater, 9(5):345-349, 1971.

254. U.S. Department of Agriculture. Soil Conservation Service. Standards and Specification for Soil Erosion and Sediment Control in Developing Areas. College Park, Maryland, 1975. 72 pp.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
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EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
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CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

255. Soil Conservation Service. Drainage of Agricultural Land. SCS National Engineering Handbook, Section 16, U.S. Dept. of Agriculture, 1971. 52 pp.

256. American Society of Agricultural Engineers. Evapotranspiration and Its Role in Water Resource Management. Conference Proceedings, St. Joseph, Michigan, 1966. 10 pp.

257. Bennet, F. W. and R. L. Donahue. Methods of Quickly Vegetating Soils of Low Productivity. EPA-440/9-75-0026, U.S. Environmental Protection Agency, Washington, D.C., 1975. 85 pp.

258. Flower, F. B., I. A. Leone, E. F. Gilman, and J. J. Arthur. Vegetation Kills in Landfill Environs. In: Management of Gas and Leachate in Landfills. EPA-600/9-77-026, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. pp. 218-236.

259. Lutton, R. J. Evaluating Cover Systems for Solid and Hazardous Waste. EPA SW-867, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980. 57 pp.

260. Schwab, G. O., R. K. Frevert, K. K. Barnes, and T. W. Edminster. Elementary Soil and Water Engineering. John Wiley and Sons, New York, 1971. p. 316.

261. Ho, S., W. C. Boyle, and R. K. Ham. Chemical Treatment of Leachates from Sanitary Landfills, Journal WPCF, 46(7): 1810-1816, 1974.

262. Chian, E. S. K. and F. B. DeWalle. Evaluation of Leachate Treatment, Volume II, Biological and Physical-Chemical Processes. EPA-600/2-77-1866, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 125 pp.

263. Giddings, T. The Lycoming County, Pennsylvania Sanitary Landfill: State-of-the-Art in Groundwater Protection. Groundwater, 15(13), 21-24, 1977.

264. Pohland, F. G. Sanitary Landfill Stabilization with Leachate Recycle and Residual Treatment. EPA-600/2-75-043, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 105 pp.

265. Leckie, J. O. and J. G. Pacey. Accelerated Refuse Stabilization Through Controlled Moisture Application. In: Second Annual National Conference of Environmental Engineering Research, Development and Design, Gainesville, Florida, July, 1975. 27 pp.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

266. Pound, C. E., R. W. Crites, and D. A. Griffes. Costs of Wastewater Treatment by Land Application. EPA-430/9-75-003. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 156 pp.

267. Chian, E. S. K., and F. B. DeWalle. Sanitary Landfill Leachates and Their Treatment. J. of Environmental Engineering Division, ASCE, 102(EE2):411-433, 1976.

268. Steiner, R. L., J. D. Keenan, and A. A. Fungaroli. Demonstrated Leachate Treatment, Report on a Full-Scale Operating Plant. EPA SW-758, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1979. 70 pp.

269. Plehn, S. W. Guidelines for Landfill Disposal of Solid Waste (40 CFR Part 24). U.S. Environmental Protection Agency, Washington, D. C., 1979. 185 pp.

270. Coal Ash Disposal Manual, Report No. FP-1257. Electric Power Research Institute, Palo Alto, California, 1979. 300 pp.

271. Alzaydi, A. Flow of Gases Through Porous Media. Ph.D. Dissertation, The Ohio State University, Columbus, Ohio, 1975. 167 pp.

272. Rai, I. S. Mathematical Modeling and Numerical Analysis of Flow of Gases Around Sanitary Landfills. Ph.D. Dissertation The Ohio State University, Columbus, Ohio, 1975. 110 pp.

273. Moore, C. A. Theoretical Approach to Gas Movement Through Soils. In: Gas and Leachate from Landfills. EPA-600/9-76-004, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. pp. 33-43.

274. Moore, C. A. Landfill Gas Generation, Migration, and Control Critical Reviews in Environmental Control, 9(2):94-102, 1979.

275. Pountney, P. J. and H. Turner. Hydrogen Peroxide Makes an Excellent Sludge Deodorant. Water & Wastes Engineering, 10(1):56-59, 1979.

276. Strunk, W. G. Hydrogen Peroxide Treats Diverse Wastewaters. Industrial Wastes, 3(1):32-35, 1979. pp. 32-35.

TYPING GUIDE SHEET
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TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

277. Warburton, D. J., J. N. Scarborough, D. L. Day, A. J. Muehling, S. E. Curtis, and A. H. Jensen. Evaluation of Commercial Products for Odor Control and Solids Reduction of Liquid Swine Manure. Paper presented at the Illinois Livestock Waste Management Conference, March 6, 1979, Champaign, Illinois. 7 pp.

278. Sultan, H. A. Soil Erosion and Dust Control on Arizona Highways, Part I. State-of-othe Art Review. Arizona Department of Transportation, Report RS-10-141-1, Phoenix, Arizona, October, 1974. 132 pp.

279. Wishmeiser, W. H. and D. D. Smith. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. U.S. Dept. of Agriculture, Agr. Handbook No. 537, 1972. 58 pp.

280. Skidmore, E. L. and N. P. Woodruff. Wind Erosion Forces in the United States and Their Use in Predicting Soil Loss. U.S. Dept. of Agriculture, Handbook No. 346, Washington, D.C., 1968. 42 pp.

281. Dawson, J. F. Control of Damage by Muskrats to Earth Structures. M. S. Thesis, University of Saskatchewan, 1950. 78 pp.

282. Sherard, J. L. Failures and Damages. In: Earth and Earth Rock Dams, Wiley and Sons, New York, 1963. pp. 113-199.

283. Curran, C. H. The Families and Gendra of North American Diptera. Bellam Press, New York, N.Y., 1934. 125 pp.

284. Gotass, H. B. Composting: Sanitary Disposal and Reclamation of Organic Wastes. World Health Organization Monogram Series 31, World Health Organization, Geneva, 1956. 31 pp.

285. Golueke, C. G. and H. B. Gotaas. Public Health Aspects of Waste Disposal by Composting. American Journal of Public Health, 44(3):339-348, 1954.

286. Boswell, A. M. and S. L. Neave. Laboratory Studies of Sludge Digestion. In: Illinois State Water Survey Bulletin No. 20. Illinois State Department of Water Resources, Springfield, Illinois, 1939. 29 pp.

287. Herpens, H. and E. Herpens. Importance of Production and Utilization of Sewage Gas. KWG-KOHL-Enwosse-Stoffgase. 72(18):34-36. 1966.

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288. Merz, R. C. Investigation to Determine the Quantity and Quality of Gases Produced During Refuse Decomposition. State Water Quality Control Board, Sacramento, California, 1964. 65 pp.

289. Jackson, A. G. Evaluation of Sanitary Landfill Gas and Leachate Production. System Technology Corporation, Dayton, Ohio, 1975. 72 pp.

290. Golueke, C. G., and P. H. McGauhey. Comprehensive Studies of Solid Waste Management, First Annual Report. U.S. Public Health Service, Bureau of Solid Waste Management, Report SW-3RG, Washington, D.C., 1970. 89 pp.

291. Hazeltine, T. R. Addition of Garbage to Sewage. Water and Sewage Works J., 86(5):151-155, 1951.

292. Duggan, J. C. and D. H. Scanlon. Effects of Decomposition Gases on Landfill Revegetation at TVAs Land Between the Lakes. In: Management of Gas and Leachate in Landfills. EPA-600/9-77-026, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. pp. 275-278.

293. Boyle, W. C., and R. K. Ham. Biological treatability of Landfill Leachate. J. Water Pollution Control Federation, 46(15):860-872, 1974.

294. DeWalle, F. B. and E. S. K. Chian. Leachate Treatment of Biological and Physical Methods - Summary of Laboratory Experiments. In: Management of Gas and Leachate in Landfills. EPA-600/9-77-026, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. pp. 177-186.

295. Jones, J. L., D. C. Bomberger, and F. M. Lewis. Municipal Sludge Disposal Economics. Environ. Sci. and Tech., 11(10):43-49, 1977.

296. Greeley and Hansen, Inc. Report on Management and Disposition of By-Product Solids. Tampa Department of Sanitary Sewers, 1975. 202 pp.

297. Engineering-Science, Inc. and J. B. Gilbert and Associates. An Analysis of the Sewage Sludge Disposal Problem in Southern California. U.S. Environmental Protection Agency, Washington, D. C., 1974. 135 pp.

298. Engineering-Science, Inc. Demonstration of a Planning Perspective for Waste Water Sludge Deposition: Knoxville/Knox County. Tennessee. U.S. Environmental Protection Agency, Washington, D.C., 1975. 95 pp.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

299. Chian, E. S. K. and F. B. DeWalle. Evaluation of Leachate Treatment, Volume I, Characterization of Leachate. EPA-600/2-77-186a, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 203 pp.

300. Nisbet, I. C. F. Criteria Document for PCB's. EPA-440/9-76-021. U.S. Environmental Protection Agency, Washington D.C. 1976. 124 pp.

301. Solid Waste Disposal and Control. Publication NO. 304. World Health Organization, Geneva, Switzerland, 1971. 35 pp.

302. SCS Engineers. Design and Operation Manual for Wastewater Treatment Sludge Landfills, Interim Report, Volume III: Site Selection, Design, Operation. Contract No. 68-01-4625. U.S. Environmental Protection Agency, Washington, D. C., 1978. 178 pp.

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APPENDIX A

SLUDGE LEACHATE COMPOSITION REPORTED IN LITERATURE

The footnotes below are the footnotes for the following table.

[a] where: FTC = field test cell
Field = field study at landfill site
Lab = laboratory column or extraction testing

[b] where: An.D. = anaerobically digested; D = digested; CHC = chemically conditioned; S.T. = septic tank pumpings; RP = raw primary; WA = waste activated sludge; and Ash = incinerator ash.

[c] where: A = sludge-only trench, covered with soil
B = sludge is lagooned, allowed to dry, and covered with soil
C = dewatered sludge is mixed with refuse, compacted and covered with soil
D = sludge dumped into trench, covered with refuse and soil
E = liquid sludge is poured on refuse, covered with soil
F = liquid sludge is poured on refuse, covered with soil
G = sludge is dried in piles, spread with refuse, covered with soil

[d] proportion based on wet weight

[e] in mg/l, except where indicated otherwise

[f] MPN (most probable number)/100 ml

[g] Based on BOD total

APPENDIX A

SLUDGE LEACHATE COMPOSITION REPORTED IN LITERATURE

Researcher	Pickart (89) Cell 4	Pickart (89) Cell 3	Pickart (89) Cell 2	Pickart (89) Cell 8
Type of Study[a]	FTC	FTC	FTC	FTC
Type of Residual[b]	An.D. (<5%)	An.D. (<5%)	An.D. (<5%)	An.D. (<5%)
Disposal Method[c]	F	F	F	F
Mix Ratio[d] (Sludge/refuse)	7/4	2/1	1/1	1/1
Time Since Closure (Months)	1-9	1-9	4-9	4-9
Depth of Fill (ft)	6	6	6	6
Leachate Composition[e]				
COD	1820-53,260	6210-59,280	5060-36,620	1920-14,440
BOD_5				
TOC				
TS	6290-17,440	8700-20,500	7900-21,640	6510-16,580
TDS	6050-16,960	8570-20,120	7750-21,490	6920-16,330
Sp. Cond. (μmhos/cm)	12,440-20,550	14,000-20,010	9900-24,400	11,300-16,160
Alk. as $CaCO_3$				
Hard. as $CaCO_3$				
Total P	5.9-37.0	4.5-63	2.7-12.6	4.5-41.7
Total N				
NH_4-N	660-1600	1275-1485	610-1760	120-1450
NO_3 -N	3.3-10.6	4.3-9.6	4.0-8.7	2.0-25.9
Cl				
SO_4				
Ca				
Mg				
Na				
K				
Fe (total)				
Zn				
Cu				
Cd				
Pb				
Ni				
Mn				
Cr (total)				
Hg				
Ag				
Fecal Coliform[f]	200-33,000	1800-1.8×10^5		800-26,000
Fecal Strep.[f]				
pH	6.6-9.9	5.7-9.0	7.4-9.4	7.3-8.3

APPENDIX A

SLUDGE LEACHATE COMPOSITION REPORTED IN LITERATURE

Researcher	Pickart (89) Cell 9	Pickart (89) Cell 10	Pickart (89) Cell 11	Emcon (90) Cell E
Type of Study[a]	FTC	FTC	FTC	FTC
Type of Residual[b]	An.D. (<5%)	An.D. (<5%)	An.D. (<5%)	S.T.
Disposal Method[c]	F	F	F	E
Mix Ratio[d] (Sludge/refuse)	2/1	7/4	1/1	NI (not indicated)
Time Since Closure (Months)	1-9	1-9	4-9	16
Depth of Fill (ft)	3	3	3	NI
Leachate Composition[e]				
COD	950-42,130	2485-47,240	130-26,110	36,120-86,420
BOD_5				19,000-38,250
TOC				
TS	4260-20,070	6630-28,400	5200-21,600	
TDS	4220-19,750	6590-28,080	5190-21,250	25,688-29,070
Sp. Cond. (umhos/cm)	7900-19,140	13,700-21,620	130-23,420	12,000-19,000
Alk. as $CaCO_3$				5983-11,583
Hard. as $CaCO_3$				
Total P	4.1-61.6	4.8-135	2.5-17.5	
Total N				923-1432
NH_4-N	580-1080	615-1420	590-1390	0-870
NO_3-N	3.3-21.0	5.2-11.0	3.4-13.9	0.01-1.0
Cl				1600-4648
SO_4				460-1271
Ca				100-2700
Mg				0-950
Na				100-1300
K				0-1400
Fe (total)				514-1083
Zn				64-91
Cu				
Cd				
Pb				0.41-0.70
Ni				
Mn				
Cr (total)				
Hg				
Ag				
Fecal Coliform[f]	490-110,000	500-110,000	500-50,000	<3
Fecal Strep.[f]				<3-1100
pH	7.2-9.4	5.9-9.2	7.6- 8.4	4.6-5.7

APPENDIX A

SLUDGE LEACHATE COMPOSITION REPORTED IN LITERATURE

Researcher	SCS Engineers (92) Site 1	SCS Engineers (92) Site 2	SCS Engineers (92) Site 3	SCS Engineers (92) Site 4
Type of Study^a	Field	Field	Field	Field
Type of Residual^b	RP, WA (25-30%)	RP, WA (20-25%)	RP, WA (25-40%)	RP,WA,ChC(18-25%)
Disposal Method^c	C	D	A	A
Mix Ratio^d (Sludge/refuse)	1/7	1/10	Sludge-only	Sludge-only
Time Since Closure (Months)	Active	Active	Active	Active
Depth of Fill (ft)	24	30	NI	NI
Leachate Composition^e				
COD		2000-5637	14,552-23,283	5443-10,998
BOD_5				
TOC	985	1067-2750	1030-14,257	227-4960
TS		452-12,465	5805-13,290	5411-23,760
TDS				
Sp. Cond. (μmhos/cm)	6900-18,000		520-6900	520-6900
Alk. as $CaCO_3$				
Hard. as $CaCO_3$				
Total P				
Total N		80-161	759-3545	1058-1459
NH_4-N		57-130	605-3407	986-1432
NO_3 -N		<0.02-0.02		<0.02
Cl		4-576	28-1160	508-680
SO_4	8	1-1600	1-430	1-60
Ca		77-510	111-2070	317-2248
Mg				
Na				
K				
Fe (total)	190	0.75-64	6.5-24.8	12-350
Zn	11	0.01-1.40	<0.01-1.80	0.04-0.29
Cu	< 0.01	<0.01-0.10	<0.01-0.054	<0.01-36.34
Cd	0.003	0.003-0.025	0.002-0.021	0.003-0.216
Pb	0.10	0.10-1.40	0.03-0.73	0.02-3.53
Ni	0.04	0.08-0.20	0.02-0.30	0.07-0.18
Mn				
Cr (total)	0.01	0.01-0.47	0.04-0.17	0.08-51.64
Hg	< 0.0002	< 0.0002-0.033	0.001-0.012	0.0002-0.005
Ag				
Fecal Coliform^f		3-≥2400	≥2400-≥24,000	≥2400-≥24,000
Fecal Strep.^{f}		460- ≥ 2400	≥2400-≥240,000	>2400->24,000
pH		6.9-7.9	6.7-7.6	7.1-8.3

APPENDIX A

SLUDGE LEACHATE COMPOSITION REPORTED IN LITERATURE

Researcher	SCS Engineers (92) Site 7	SCS Engineers (92) Site 8	Stone (39) Cell 1	Stone (39) Cell 3
Type of Study[a]	Field	Field	FTC	FTC
Type of Residual[b]	RP,WA (20-40%)	RP,WA	RP(2-10%)	D
Disposal Method[c]	G	B	E	E
Mix Ratio[d] (Sludge/refuse)	1/5	Sludge-only	-1/5	- 1/5
Time Since Closure (Months)	Active	Active	0-18	0-18
Depth of Fill (ft)	24	8	13	13
Leachate Composition[e]				
COD	1345-4505	1194-8265		
BOD_5			9200-34,800	10,900-28,700
TOC	118-1333	890-3000		
TS	3736-4413			
TDS			16,000-33,000	16,896
Sp. Cond. (umhos/cm)			18,000-29,500	7,850-10,400
Alk. as $CaCO_3$			5550-11,500	6570
Hard. as $CaCO_3$			5200-8200	5900
Total P				
Total N	510-555	254		
NH_4-N	482-521	198	583	
NO_3 -N	0.03-0.12	0.28	3.2-13.0	0.85
Cl	3-1283	3	600-5944	566-1589
SO_4	<1.0-15	12	723-1047	689
Ca	115-198	43-617	1380-1960	1400
Mg			425-802	583
Na			1320-1750	
K			610-700	375
Fe (total)	1.1-126	63-320	2.4-113	107
Zn	0.06-0.26	0.26-17.0		
Cu	<0.01-0.13	0.31-4.90	<0.05-0.81	
Cd	<0.001-0.010	0.002-0.033		
Pb	0.03-0.364	0.07-2.0	<0.05-0.20	0.18
Ni	0.04	0.02-1.10		
Mn			0	0
Cr (total)	0.05-2.93	0.09-5.62	0.10	0.08
Hg	0.0002-0.0007	<0.0002-<0.001		
Ag				
Fecal Coliform[f]	20-1100	≥2400-24,000		
Fecal Strep.[f]	4300-≥240,000	2100-≥24,000		
pH	7.5-7.7	6.2-7.2	4.8-5.29	4.8-5.15

APPENDIX A

SLUDGE LEACHATE COMPOSITION REPORTED IN LITERATURE

Researcher	Johansen *et al.* (91) Ist II	Johansen *et al.* (91) Ist I	Johansen *et al.* (91) Gronmo	Johansen *et al.* (91) Branas.
Type of Study[a]	Field	Field	Field	Field
Type of Residual[b]	NI(>10%)	NI(>10%)	NI(> 10%)	NI(>10%)
Disposal Method[c]	E	C	G	G
Mix Ratio[d] (Sludge/refuse)	NI	NI	NI	NI
Time Since Closure (Months)	Active	<12	Active	Active
Depth of Fill (ft)	10	45	54	15
Leachate Composition[e]				
COD	110-245	215-825	470-520	825-1080
BOD_5	50[g]			
TOC	30	180	100	250
TS	610	3880	2960	2730
TDS				
Sp. Cond. (µmhos/cm)	655	3050	3310	3210
Alk. as $CaCO_3$	310	1550	1500	2050
Hard. as $CaCO_3$				
Total P	0.1	3.3	0.6	1.7
Total N	16.6	80-155	155-182	254
NH_4-N	10.2	141	120	225
NO_3 -N	0.79	0.02	0.04	0.01
Cl	68	590	680	280
SO_4	41	37	30	10
Ca	99	173	188	198
Mg	13	58	66	96
Na	34.8	312	462	229
K	21.3	129	200	172
Fe (total)	11.5	10.2-37.7	67.6-84.2	78.0
Zn	0.12	0.085	0.055	0.095
Cu	0.0008	0.009	0.085	0.011
Cd	0.0005	0.002	0.005	0.0001
Pb	0.001	0.001	0.004	0.001
Ni	0.005	0.015	<0.1	0.02
Mn				
Cr (total)	0.002	0.027	0.023	0.035
Hg				
Ag				
Fecal Coliform[f]				
Fecal Strep.[f]				
pH		7.0	6.8	6.9

APPENDIX A

SLUDGE LEACHATE COMPOSITION REPORTED IN LITERATURE

Researcher	LACSD (37)	Bradford *et al.* (93)	Sweeney (94)	Sikora *et al.* (83)
Type of Study[a]	Lab	Lab	Lab	Field
Type of Residual[b]	An.D,RP,WA	NI	Ash	RP, Lime
Disposal Method[c]	C			A
Mix Ratio[d] (Sludge/refuse)	NI	Sludge-only	Sludge-only	Sludge-only
Time Since Closure (Months)	<12			
Depth of Fill (ft)	25-100(simulated)			
Leachate Composition[e]				
COD	8005			
BOD_5	1828			
TOC				
TS				
TDS	9719			
Sp. Cond. (μmhos/cm)	13,200	4000-10,000		
Alk. as $CaCO_3$	5320			
Hard. as $CaCO_3$	2490			
Total P	100			
Total N	981			
NH_4-N	750			<0.2
NO_3 -N	<0.1			0.1-6.8
Cl	494		0.25-21.0	3-34
SO_4	160		0-8600	
Ca	1420		2.30-893	
Mg	1070		0.30-655	
Na	754		0.96-1187	
K	990		0.47-358	
Fe (total)	34		0-0.21	
Zn	20.7	0.0005-0.0015		
Cu	1.09	0.00014-0.0016	0-0.16	
Cd	0.072	5×10^{-5}-0.0012		
Pb	1.20	0.00013-0.002	0	
Ni	0.98	0.00018-0.018	0-0.22	
Mn	2.50		0-0.18	
Cr (total)		<1.0		
Hg				
Ag				
Fecal Coliform[f]				
Fecal Strep.[f]				
pH	7.7		6.37-8.10	

APPENDIX A

SLUDGE LEACHATE COMPOSITION REPORTED IN LITERATURE

Researcher	Lund *et al* (113)
Type of Study[a]	Field
Type of Residual[b]	NI
Disposal Method[c]	B
Mix Ratio[d] (Sludge/refuse)	Sludge-only
Time Since Closure (Months)	240
Depth of Fill (ft)	
Leachate Composition[e]	
COD	
BOD_5	
TOC	
TS	
TDS	
Sp. Cond. (umhos/cm)	
Alk. as $CaCO_3$	
Hard. as $CaCO_3$	
Total P	
Total N	
NH_4-N	
NO_3-N	0.3 - 400
Cl	
SO_4	
Ca	
Mg	
Na	
K	
Fe (total)	
Zn	
Cu	
Cd	
Pb	
Ni	
Mn	
Cr (total)	
Hg	
Ag	
Fecal Coliform[f]	
Fecal Strep.[f]	
pH	

APPENDIX A

RANGE OF REPORTED VALUES

Researcher	Sludge-Only Landfill*	Refuse-Only Landfill	Sludge/Refuse Codisposal
Type of Study[a]			
Type of Residual[b]			
Disposal Method[c]			
Mix Ratio[d] (Sludge/refuse)			
Time Since Closure (Months)			
Depth of Fill (ft)			
Leachate Composition[e]			
COD	1194-23,283	40-89,520	110-86,420
BOD_5		81-33,360	1828-38,250
TOC	227-14,267	256-28,000	30-14,440
TS	5411-23,760	0-59,200	610-28,400
TDS		584-44,900	5190-33,000
Sp. Cond. (μmhos/cm)	520-10,000	2810-16,800	130-29,500
Alk. as $CaCO_3$		0-20,850	310-11,583
Hard. as $CaCO_3$		0-22,800	2490-8200
Total P		0-398	0.1-135
Total N	254-3545	0.10-3600	16.6-1485
NH_4-N	198-3407	0-1105	10.2-1760
NO_3 -N	<0.02-400	0.14-10.3	0.01-25.9
Cl	3.0-1160	4.7-2467	3-5944
SO_4	1-430	1-1558	<0.1-1600
Ca	43-2248	60-7200	77-1420
Mg		17-15,600	37-1070
Na		0-7700	34-1750
K		28-3770	21.3-700
Fe (total)	6.5-350	0-2820	0.75-1083
Zn	0.0005-17	0-370	<0.01-91
Cu	0.00014-36.3	0-9.9	0.0008-0.81
Cd	5×10^{-5}-0.22	0.03-17	0.0001-0.072
Pb	0.00013-3.53	<0.10-2.0	0.001-1.40
Ni	0.00018-1.10	0-0.81	0.005-0.98
Mn		0.09-125	0-2.50
Cr (total)	0.04-51.6		0.002-2.93
Hg	< 0.0002-0.012		<0.0002-0.033
Ag			
Fecal Coliform[f]	≥2400-≥24,000	$0-10^6$	$<3.0-1.8\times10^5$
Fecal Strep.[f]	2100-≥24,000	$0-10^5$	$<3-2.4\times10^5$
pH	6.2-8.3	3.7-8.5	4.5-9.9

* excluding incinerator ash

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APPENDIX B

LEGEND FOR REFERENCES SHOWN IN FIGURES 13-24

Reference No. Indicated in Figures	Actual Reference
1	SCS Engineers (92) Site 1
2	SCS Engineers (92) Site 2
3	SCS Engineers (92) Site 3
4	SCS Engineers (92) Site 4
5	SCS Engineers (92) Site 7
6	SCS Engineers (92) Site 8
7	Stone (39), Cell 1 @ ∿ 1 year
8	Stone (39), Cell 1 @ ∿ .5 year
9	Stone (39), Cell 1 @ ∿ 2.0 years
10	Stone (39), Cell 3 @ 1.5 years
11	Stone (39), Cell 3 @ 2.0 years
12	Pickart (89), Cell 2
13	Pickart (89), Cell 3
14	Pickart (89), Cell 4
15	Pickart (89), Cell 8
16	Pickart (89), Cell 9
17	Pickart (89), Cell 10
18	Pickart (89), Cell 11
19	Johansen et al. (91), Grommo
20	Johansen et al. (91), Branasdalen
21	Johansen et al. (91), Isi I
22	Johansen et al. (91), Isi II
23	Los Angeles County Sanitation District (37)
24	Emcon Associates (90)
25	Chian and DeWalle (299)
26	Sikora et al (83)
27	Lund et al (113)
28	Ware (33)

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APPENDIX C. SPECIFIC DOSE/RESPONSE RELATIONSHIPS FOR VARIOUS MICROORGANISMS AND SUBJECTS (159)

Host	Organism	Dose	How Administered	Response
Guinea pigs	B. anthracis	15,000 org.* (<1 μm)+	inhalation	LD_{50}#
Guinea pigs	B. anthracis	60,000 org. (<3 μm)	inhalation	LD_{50}
Guinea pigs	B. anthracis	400,000 org. (<7 μm)	inhalation	LD_{50}
Guinea pigs	B. anthracis	900,000 org. (<11μm)	inhalation	LD_{50}
Guinea pigs	P. tulurensis	3 org. (1 μm)	inhalation	LD_{50}
Guinea pigs	P. tulurensis	6,500 org. (7 μm)	inhalation	LD_{50}
Guinea pigs	P. tulurensis	20,000 org. (12 μm)	inhalation	LD_{50}
Guinea pigs	P. tulurensis	170,000 org. (22 μm)	inhalation	LD_{50}
Rhesus monkeys	P. tulurensis	17 org. (1 μm)	inhalation	LD_{50}
Rhesus monkeys	P. tulurensis	240 org. (7 μm)	inhalation	LD_{50}
Rhesus monkeys	P. tulurensis	540 org. (12 μm)	inhalation	LD_{50}
Rhesus monkeys	P. tulurensis	3,000 org. (22 μm)	inhalation	LD_{50}
Human	Typhoid	10^3 org.	oral	no infection
Human	Typhoid	10^7 org.	oral	LD_{50}
Human	Shigella	10 org.	oral	infection
Human	Typhoid and other salmonellae	10^5 org.	oral	infection
Human	E. coli or V. cholerae	10^8 org.	oral	infection
Human	Salmonellae and S. typhae	10^5 org.	oral	infection
Human	Shigella	10 to 100 org.	oral	infection

(continued)

APPENDIX C. (CONTINUED)

Host	Organism	Dose	How Administered	Response
Hamster	Influenza and parainfluenza	320 TCD$_{50}$	aerosolized	100% infection
Hamster	Influenza and parainfluenza	32 TCD$_{50}$	aerosolized	100% infection
Hamster	Influenza and parainfluenza	3.2 TCD$_{50}$	aerosolized	67% infection
Hamster	Influenza and parainfluenza	0.3 TCD$_{50}$	aerosolized	33% infection
Hamster	Influenza and parainfluenza	0.03 TCD$_{50}$	aerosolized	no infection
Egg	Influenza and parainfluenza	5 EID$_{50}$ ‡	injection	infection
Egg	Influenza and parainfluenza	0.45 EID$_{50}$	injection	infection
Human	Parainfluenza	100 TCD$_{50}$	internasal injection	65% infection
Human	Parainfluenza	80 TCD$_{50}$	internasal injection	75% infection
Human	Parainfluenza	1.5 TCD$_{50}$	internasal injection	100% infection
Human	Parainfluenza	15 TCD$_{50}$	internasal injection	no infection
Human	Parainfluenza	2,000 TCD$_{50}$	internasal injection	no infection
Human	Parainfluenza	20,000 TCD$_{50}$	internasal injection	infection
Human	Rhinoviruses	30 to 10,000 TCD$_{50}$	internasal injection	not given
Human	Rhinoviruses	<1 TCD$_{50}$	internasal injection	40% infection
Human	Rhinoviruses	16 TCD$_{50}$	internasal injection	not given
Human	Measle virus	10 TCD$_{50}$	intranasal spray	89% infection
Human	Measle virus	6 TCD$_{50}$	intranasal spray	69% infection
Human	Measle virus	2 TCD$_{50}$	intranasal spray	49% infection
Human	Measle virus	1 TCD$_{50}$	intranasal spray	23% infection
Human	Measle virus	0.6 TCD$_{50}$	intranasal spray	>12% infection
Human	Measle virus	0.2 TCD$_{50}$	intranasal spray	>14% infection
Human	Measle virus	0.1 TCD$_{50}$	intranasal spray	no infection

(continued)

APPENDIX C (CONTINUED)

Host	Organism	Dose	How Administered	Response
Pig	Total count	1.3×10^5 to 3.5×10^5 colony forming plates per m^3 (CFP)	inhalation	no infection
Pig	Fecal coliform	1.9×10^3 to 2.4×10^4 (CFP)	inhalation	no infection
Human	Polio virus	200 PFU (plaque forming units)	oral	100% infection
Human	Polio virus	20 PFU	oral	100% infection
Human	Polio virus	2 PFU	oral	<66% infection
Human	Polio virus	0.2 PFU	oral	0% infection
Human infants	Polio virus	100 TCD_{50} to 1,000 TCD_{50}	oral	100% infection
Human infants	Polio virus	30 TCD_{50} to 100 TCD_{50}	oral	77% infection
Human infants	Polio virus	10 TCD_{50}	oral	66% infection
Mice	Coxsaic viruses	30 TCD_{50}	inhalation	infection
Mice	Coxsaic viruses	18 TCD_{50}	inhalation	infection
Human	Coxsaic viruses	100 TCD_{50}	intransally	50% infection
Human	Coxsaic viruses	50 TCD_{50} ($< 3\mu$)	inhalation	70% infection 100% respiratory infection
Human	Adenoviruses	1000 TCD_{50}	transmitted by upper respiratory tract	infection
Human	Infectious hepatitis	0.1 g of feces from the infected patients	oral	infection
Human	Infectious hepatitis	0.01 g of feces from the infected patients	oral	no infection

(continued)

APPENDIX C (CONCLUDED)

Host	Organism	Dose	How Administered	Response
Human	Polio virus	2 PFU	oral	70% infection
Human	Polio virus	20 PFU	oral	100% infection
Human	Polio virus	100 TCD_{50}	oral	infection
Human	Polio virus	10 TCD_{50}	oral	infection
Human	Coxsackie	18 TCD_{50}	Respiratory route	infection
Human	Coxsackie	1.5 TCD_{50}	Respiratory route	infection
Human	Adenovirus	<150 TCD_{50}	Respiratory route	infection
Human	Parainfluenza	0.5 TCD_{50}	Respiratory route	infection
Human	Parainfluenza	1.5 TCD_{50}	Respiratory route	infection
Human	Parainfluenza	2,000 to 20,000 TCD_{50}	Respiratory route	infection
Human	Influenza	790 TCD_{50}	Respiratory route	infection
Human	Measles	15 TCD_{50}	Respiratory route	infection

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[*] Organisms-Most Probable Number (MPN)

[+] diameter, aerosol droplet

[#] Median lethal dose, or the dose of a test material, ingested or injected, that kills 50% of a group of kst organisms.

‡ Egg Infective Dose

APPENDIX D

PRELIMINARY TESTING FOR APPRAISING LEACHING HAZARDS AND APPLICATION RATES AT SLUDGE BURIAL SITES

The leaching hazards presented by a given sludge at a particular site can be deomonstrated by the following leaching tests. Two tests are laboratory leaching studies; the third is a field study. The laboratory tests are intended to simulate field conditions, using soils sampled from each horizon in the zone of aeration. However, the kinetics of water and solute movement in a bench scale test cannot ordinarily approximate field conditions, where precipitation is intermittent and the intact soil profile retains its unique physical characteristics. Laboratory testing can establish the relative mobility of a sludge constituent in various soil horizons. By testing for sludge constituents mobilities in lower horizons, one could determine whether rapid movement of a sludge constituent through a less absorptive surface soil may be impeded by a more absorptive subsoil. In the case of organic constituents such as pesticides, information can be gained as to their degredative capability in each profile.

OIL THIN LAYER CHROMATOGRAPHY (TCL)

In this test, the mobility of a given substance can be expressed by a relative measure, R_F, which describes the distance traversed by a compound of interest divided by the distance traversed by the wetting front. the procedure is outlined as follows (234):

(1) Soil materials utilized are those passing a 500 mm sieve for sandy clays and coarser textured soils, or 250 μm sieve for fine loams and clay soils.

(2) A smooth, moderately fluid slurry is made of water and sieved soil material and spread on clean glass plates to uniform thicknesses of 500-750 μm for fine textured soils, and 750-1000 μm for the coarser textured soils. Plates are air-dried before use.

(3) A horizontal line is etched 11.5 cm above the base. Samples are spotted at 1.5 cm, providing a total leaching distance of 10 cm.

(4) The developing chamber's atmosphere is allowed to saturate and equilibrate prior to plate development.

(5) Plates are developed in a vertical position in approximately 0.5 cm water. The bottom cm may be covered with a filter paper strip to reduce soil sloughing and maintain the soil-water contact. Development continues until water has risen to the scribed line at 11.5 cm.

(6) Movement is determined by either radio-autograms for radioactive materials or scraping and eluting segments of soil from the 10 cm development distance. Scraped materials can be easily eluted with small volumes of solvent by using capillary pipettes as elution columns.

(7) R_F values are computed and correlated to soil properties.

Soil TLC is a useful rapid screening technique, but where waste constituents are mobile as indicated by R_F values, soil column leaching and field pilot studies will be necessary to better quantify mobility in a more realistic system (234).

COLUMN LEACHING

A soil column offers a better approximation to a natural system than does a TLC since the column provides a larger soil volume, larger aggregates, and a more random particle orientation. However, soil column leaching tests lack the methodological standardization of soil TLC (234).

The general procedure is as follows. At a minimum, duplicate columns and a control should be utilized for each treatment.

(1) Fill glass columns (2-3 cm I.D.) with 20 cm air-dry soil previously ground and passed through a 2 mm mesh sieve. Columns should be constructed of glass or other non-reactive material which does not interfere with the analyses.

(2) Columns are filled slowly and tamped to a bulk density approximating that in the field to reduce solution movement by direct channel transport and to more closely resemble field conditions.

(3) Applications of sludge to the soil should simulate field methods, i.e., by mixing sludge with a small amount of soil and burying the mix in the column, or applying the sludge without mixing.

(4) Put glass wool or a filter pad on the soil surface and begin leaching by adding at least one column volume of water at a controlled rate.

(5) Effluents are analyzed along with the soil extruded and segmented at 2 cm intervals to evaluate depth of penetration as a function of the effective volume partitioned. The volume partitioned can be assumed to be the volume of water retained by the soil at field capacity. Thus an effluent volume equal to the volume of water retained at 1/3 atmosphere soil moisture tension approximates 1 pore volume.

(6) Concentrations of material in effluent are determined and plotted against cumulative drainage volume.

The potential leaching hazard of a given sludge in a particular soil can be estimated from consideration of (234):

(1) The mobility of sludge constituents relative to water;

(2) The concentrations of constituents observed in the leachate and soil;

(3) The degradability of mobile organic compounds;

(4) The flux and depth of soil solution percolate as observed in the field water balance.

Column tests have several disadvantages, such as (234):

(1) Problems arising from channeling and nonuniform packing,

(2) Potential unnatural clogging,

(3) Possibly unnatural biological effects,

(4) Edge effects,

(5) Long time requirements, and

(6) Difficulty in obtaining reproducible results even if done by experienced lab personnel.

Field pilot studies are needed to correlate and verify laboratory results and are particularly important when laboratory data reveal a substantial leaching hazard.

FIELD PILOT STUDIES

Field pilot testing is the closest approximation to actual sludge-site operational conditions. Field studies can be used to verify laboratory results, or demonstrate any conditions not adequately assessed in the laboratory. Field studies may also serve the following functions:

(1) To evaluate possible odor and vector problems;

(2) To provide information on any physical problems associated with sludge burial, such as cover soil and equipment support, soil or refuse bulking required, etc.;

(3) To evaluate the runoff water quality and the length of time required for the runoff quality to become acceptable for uncontrolled release.

Field pilot studies can provide better data than laboratory tests, though they can be more costly to conduct and fewer variables, such as type of sludge, application rate, or landfilling methods, can be tested. In addition, uncontrolled variables such as temperature, rainfall, and wind make data more difficult to interpret.

Perhaps the simplest and most inexpensive method of collecting leachate of field plots would be through well points, located below the zone of sludge incorporation. There should be little reason to sample groundwater, inasmuch as leachate is unlikely to reach it during the testing period. Runoff water should be retained and analyzed where warranted.

Application rates to be utilized in pilot studies must be based on the best available information and must be developed in accordance with appropriate procedures. If one of the objectives is to test the feasibility of application rates greater than those which would be indicated by the laboratory information, it is advisable to select treatments within 2, 4, and possibly 8 times the optimal rate. Precautions must be taken, however, not to endanger the groundwater from overloaded mobile constituents.

In summary, laboratory leaching studies and field pilot studies can be used to assess the leaching hazards posed by sludge landfill sites. Although laboratory testing can establish the relative mobility of sludge constituents, field pilot testing can more accurately simulate actual landfill conditions governing constituent migration.

APPENDIX E

ADDITIONAL RESEARCH NEEDS

An examination of existing literature on the disposal of WWTP sludge by landfilling has revealed some important deficiencies in the areas of potential environmental and public health impacts. In order to rectify these deficiencies, this section will (1) identify those areas requiring additional research, (2) suggest specific objectives of the future research in these areas, and (3) recommend approaches to satisfy these research needs.

Suggested research approaches will be designated by one or more of the following categories:

- Basic research - identification of the physical, chemical or biological processes or mechanisms that occur in landfilling of WWTP sludges.
- Bench scale - experiments performed within the laboratory, usually utilizing apparatus and materials which simulate landfill or field conditions.
- Field studies - studies at actual landfill sites which can be used in conjunction with bench scale experiments to verify results or improve their viability.
- Epidemiological studies - an examination of the elements contributing to the occurrence or non-occurrence of disease in site operations or in communities surrounding a WWTP sludge landfill.

In addition to the suggested topics and methods of approach, approximate costs and time appropriations necessary for completion of potential projects are estimated.

ENVIRONMENTAL RESEARCH

The potential acute and/or chronic environmental impacts resulting from the landfilling of WWTP sludge have not been given adequate attention, particularly in the areas of leachate composition and strength, and the potential for ground-water contamination. More information is available for the potential impacts resulting from mono-disposal (or sludge disposal alone) because of the research trends in the areas of sludge entrenchment, subsurface injection, and applications to agricultural land. Impacts resulting from codisposal methods are less understood.

Based upon the examination of literature, obtained in this project concerning the environmental impacts of landfilling WWTP sludges, the following areas are suggested for research consideration:

Investigation of the Contaminant Concentrations in Sludge Landfill Leachates and an Assessment of Those Factors Which Influence Contaminant Levels.

Suggested Research Objectives--

1). Determine the effects of landfilling sludge resulting from various treatment processes on leachate quality, e.g., the effects of lime conditioning, anaerobic digestion, dewatering, etc.

Recommended Approach:

Bench scale--Construct a laboratory testing column or lysimeter apparatus containing sludges of various treatment processes, and apply varying water regimes to the surface to promote leaching. Leachate strength can thus be determined as a factor of sludge type, the quantity of water applied, and age. Analytical determination should be performed for heavy metals, pathogens, nutrients, and specific organics (e.g., toxic refractories, potential organo-metallic complexing species, etc.).

Field study--Landfill sites receiving sludge may be modified to have designated locations for the disposal of specific types of residuals. A series of vacuum lysimeters are appropriate where leachate collection has not already been provided.

2). Determine the effects, if any, of sludge landfilling with and without municipal refuse on the quality and quantity of leachates, particularly for parameters such as specific organic content (e.g., toxic refractories, humic-like materials, putrescibles, organo-metallic species, etc.), heavy metals, and pathogens.

Recommended Approach:

Bench scale--Construct experimental test cells which vary the ratio of sludge/refuse, including standard cells with refuse and sludge alone. Utilize sludge from different treatment processes and construct a matrix for presentation of results. The sludge/refuse mixing methods (e.g., thoroughly mixed, layered, etc.) should also be considered in the experiment.

Field study--Field studies are not as practicable in this case because of the difficulty in monitoring mix ratios.

Investigations of the Volume and Movement of Leachates of Sludge Landfills and an Assessment of Those Factors Which Influence These Levels.

Suggested Research Objectives--

1). Determine the potential short-term leachate generation (i.e., construction drainage) and long term leachate generation from various WWTP sludges and identify changes in the physical and chemical properties of the sludge as a function of age.

Recommended Approach:

Bench scale--Testing requires the construction of a simple settlement of column whereby selected pressures simulating landfill surface loading are applied, and liquid drainage is easily collected.

2). Determine the relative permeabilities of various WWTP sludges and identify the extent to which various sludges can retard or reduce the flow of leachate from fill material.

Recommended Approach:

Bench scale--Construction of experimental test cells or laboratory columns is most applicable. Test cells should include sludges of different permeability, including incinerator ash, raw and digested sludge, coagulated and non-coagulated sludge, etc. Test cells should also measure the effects of codisposal techniques on the rates of leachate generation.

Simulated rainfall is suggested as the source of leaching fluid.

3). Determine the extent to which sludge/refuse residual codisposal methods can delay the formation of leachates as compared with landfilling sludge alone.

Recommended Approach:

Bench scale--Use experimental test cells of various sludge/refuse mix ratios. Additionally, provide experimentation of mix methods, including sludge deposition at the bottom of test cells, sludge/refuse deposition in successive layers of varying thickness, sludge thoroughly mixed with refuse, and sludge placed on top of refuse.

Studies on the Basic Properties of Sludge Leachate/Environment Interactions.

Suggested Research Objectives--

1). Study the physical, chemical or biological mechanisms of leachate contaminant migration in soils.

Recommended Approach:

Basic research--The leachate migration mechanisms are crucial to the understanding of the generic nature of leachate/soil systems. The important mechanisms may include solubilization (dissolution or precipitation), sorption, ion-exchange, complexation, redox reaction, and biodegradation. The key soil components involved in interactions include the type and % of clay, organic matter, hydrated oxides, and various geochemical fractions of metals. The key solution variables include pH, Eh, and ligands. Both batch system (the agitation of leachate/soil mixtures in bottles) and column leaching tests can be performed. Experiments should cover various factors as described above. Efforts should be centered on both single and synergistic effects. For example, tests of cadmium adsorption in leachates by soils should identify the single effect (e.g., Cd adsorbed by pure adsorbent), and synergistic effects (e.g., Cd adsorbed by a wide combination of different sorbents such as different types of clay minerals, hydrated oxides, etc.). Models or semi-quantitative descriptions of the leachate/soil interactions should also be derived for the assessment or prediction of the transport and fate of leachates in soils.

2). Determine the types and levels of organic species in sludge leachates and the stability formation constants of organometallic complexes, such that the prevalance of soluble trace metal organometallic complexes in the leachate can be estimated.

Recommended Approach:

Basic research--Sophisticated instruments (e.g., GC/MS, IR, AA and other electrochemical or optical instruments) can be used to identify the types and levels of various organic species in sludge leachates. A research area needing special emphasis is the effects of organic species on the mobilization of heavy metals in leachates. The identification of the stability formation constants of organometallic complexes is necessary to understand the prevalence of soluble trace metal in leachates.

3). Examine the migration of microbiological constituents in sludge/refuse landfills.

Recommended Approach:

Bench scale--Column lysimeters with a variety of major soil types may be used to study the attenuation of key microbiological parameters. The use of viruses and other mobile microbiological indicators would be used.

Field study--Field studies at several sludge trenching installations could be initiated to develop site data corresponding to bench scale tests. The sludge could be innoculated with indicator organisms depending upon the sludge composition. Several years of routine monitoring are needed.

4). Study the generation and composition of surface runoff from various sludge/landfill operations.

Recommended Approach:

Field study--Select several key monitoring parameters, e.g., organic indicators, heavy metals, pathogens, and nutrients, and study their concentration and flow rate of surface runoff waters from area fill and trench disposal operations. Perform routine and synoptic storm related monitoring. Relate the results to the type of sludge, landfill surface conditions (e.g., slope, type of cover soil, etc.), and intensity and duration of input water.

PUBLIC HEALTH RESEARCH

Existing epidemiological evidence available indicates that disease transmission through sludge landfilling operations may occur below the background disease transmission from all other sources. This evidence is not inclusive of potential disease transmission through ground or surface water supplies. It is reasonable to assume that certain WWTP sludges and/or landfilling practices are more conducive to disease transmission, either through vector transport, direct contact, or from pathogenic aerosols. Continued or future research in these areas is necessary. Suggested research topics include:

Investigation of the Potential for Pathogenic Aerosolization of Completed or Currently Operating Sludge Sites.

Suggested Reserach Objectives--

1). Determine which, if any, of the current sludge landfilling practices, including codisposal techniques, represents a greater public health risk from aerosolization of landfill pathogens.

Recommended Approach:

Epidemiological study--Select a number of landfill sites which utilize different construction techniques, operational procedures, and/or WWTP sludges and determine the occurrence or non-occurrence of disease in site operators and in citizens of surrounding communities and compare to controls.

Field study--Set up a system of monitoring stations along the paths of prevailing winds, upwind and downwind, from sludge landfill site or sites to monitor pathogens. The study might also determine whether specific landfill types are more susceptible for aerosols traveling greater distances, (e.g., area fill mound vs. trenching operations).

2). Examine the landfill conditions which can contribute to pathogenic aerosolization, including ambient air temperatures, wind conditions, sludge mositure content, etc.

Recommended Approach:

Bench scale--A series of controlled laboratory experiments which examines each of the aforementioned variables individually, then in pairs to determine possible synergistic effects, would be more appropriate.

Investigations of the Potential for Disease Transmission Through Vector Transport, Particularly Flies.

Suggested Research Objectives--

1). Monitor the incidence of disease at sludge landfill sites following fly reduction.

Recommended Approach:

Epidemiological study--Select a number of landfill sites with and without fly control and investigate the occurrence or non-occurrence of specific diseases in the landfill surrounding areas.

SUMMARY

The additional environmental and public health research needs for the landfilling of sludge can be summarized in Table E-1. The specific research objectives as listed have been provided with estimates of the period of performance necessary for project completion as well as corresponding costs. The cost and performance period estimates are based upon the recommended approaches to the specific objectives as presented in the previous text.

TABLE E-1. ESTIMATED TIME AND COST EXPENDITURES FOR COMPLETION OF POTENTIAL PROJECTS

Research Area	Objectives	Period of Performance (Year)	Costs (in thousands of dollars)
ENVIRONMENTAL RESEARCH			
• Investigations of the contaminant concentrations in sludge landfill leachates and an assessment of those factors which influence contaminant levels	1). Determine the effects of landfilling sludge resulting from various treatment processes	3-4 (BS)* 1.5-2 (FS)*	150-250 (BS)* 150-250 (FS)*
	2). Determine the effects of landfilling sludge with and without municipal refuse	1-1.5 (BS)	150-250 (BS)
• Investigations of the volume and movement of leachates of sludge landfills and an assessment of those factors which influence these levels	1). Determine the short and long term leachate generation	1-1.5 (BS)	50-100 (BS)
	2). Determine the relative permeabilities of various sludges and identify the extent to which various sludges can retard or reduce the flow of leachates	1-1.5 (BS)	50-100 (BS)

Continued

TABLE E-1 . (Continued)

Research Area	Objectives	Period of Performance (Year)	Costs (in thousands dollars)
	3). Determine the extent to which codisposal can delay leachate generation	1-1.5 (BS)	50-100 (BS)
• Studies on the basic properties of sludge leachates/environment interactions	1). Study the physical, chemical or biological mechanisms of leachate contaminant migration in soils	1.5-2 (BR)*	150-250 (BR)*
	2). Determine the organic species and the stability formation constants of organometallic complexes in leachates	1-2 (BR)	100-200 (BR)
	3). Examine the migration of microbiological parameters	1-1.5 (BS) 1.5-3 (FS)	80-120 (BS) 100-250 (FS)
	4). Study the surface runoff from various landfill operations	1-1.5 (FS)	80-150 (FS)

Continued

TABLE E-1. (Concluded)

Research Area	Objectives	Period of Performance (Year)	Costs (in thousands of dollars)
PUBLIC HEALTH RESEARCH			
● Investigation of the potential for pathogenic aerosolizaton of completed or currently operating sludge landfill sites	1). Determine which of current landfilling practices represent a greater potential for pathogenic aerosolization	1-2 (ES)* 1.5-2 (FS)	150-300 (ES)* 100-200 (FS)
	2). Examine the landfill conditions contributing to aerosolization	1-2 (BS)	100-150 (BS)
● Investigation of disease transmission through vector transport	1). Monitor incidence of disease following fly reduction	1-2 (ES)	100-150 (ES)

* BR = Basic Research;

BS = Bench Scale;

FS = Field Studies;

ES = Epidemiological Studies